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Contents

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ERRATA

"Preparation of potash salts from leucite and from silicates of potash,"
by Emanuele Paterno

Page 42, line 1—formula for leucite should read $K_2O \cdot Al_2O_3 \cdot (SiO_2)_2$

"Studies on the Moisture Equivalent of Soils," by J. C. Russell and W. W. Burr

Page 262—Formula 5 should read:

"$y = 2.97\,x - 0.043\,x^2$" instead of
"$y = 2.97\,x - 0.43\,x^2$"

"Soil Microbiology in 1924," by Selman A. Waksman

Page 201, line 1 of quotation should read "tendance."
Page 201, line 2 of quotation should read "acquises" and "rafraîchir."
Page 211, line 6, paragraph 2, should read "Institut Agronomique" and "Institut Rechercher Agronomiques."
Page 211, inscription, and occurring throughout article, should read "Institut Pasteur" instead of "Institute Pasteur."
Page 215, line 1, paragraph 3, should read "Institut Agronomique."
Page 249, legend should read "Beijerinck."

A MODIFIED RESPIRATION APPARATUS FOR PLANT AND SOIL STUDIES[1]

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Received for publication August 13, 1924

The respiration apparatus most extensively used in plant experiments consists of the Pettenkofer (5) or air-current type with various modifications (3, 4, 6). Strong alkaline solutions or soda-lime towers remove CO_2 from the air current, which is supplied by a suction pump or by aspirators. After being passed through the plant chamber the air is again taken through bottles containing a standard alkaline solution in which the CO_2 produced is absorbed. The amount of CO_2 is then determined by titration with a standard acid. The plant chamber usually consists of a bell jar sealed to a glass or wooden base by means of wax, paraffin, or some other sealing mixture. Under ordinary greenhouse conditions the unequal contraction and expansion of the apparatus, due to fluctuation in temperature, creates openings between the sealing wax and the glass, allowing leaks to occur. Unless the bell jar, base, and sealing mixture have the same coefficients of expansion, which is rather rare, these errors are bound to creep in. This seems to be one of the main difficulties involved in studying the biological activities of plants and soil under controlled atmospheric conditions. Investigators in this field quite often report interruptions of the experiment because of sudden discovery of leakages in the apparatus.

While studying the composition of soil gases under controlled atmospheric conditions, the writer has attempted to overcome this difficulty. A number of methods were tried until finally a respiration apparatus was modified so as to eliminate both the base and the sealing wax.

DESCRIPTION OF THE APPARATUS

The apparatus consists of two bell jars of the same kind of glass, 8 inches in diameter and 14 inches deep, connected edge to edge by a heavy rubber band, as shown in plate 1. The lower bell jar has a closed top and is inserted, mouth upward, into a pot half filled with sand in order to keep it in place.

[1] Paper No. 195 of the Journal Series, New Jersey Agricultural Experiment Stations, Department of Soil Chemistry and Bacteriology.

[2] The author wishes to express his indebtedness to Dr. J. G. Lipman and Dr. J. W. Shive for helpful suggestions given during the construction and manipulation of the apparatus. The experimental work was carried out in Dr. Shive's laboratory.

The upper bell jar has an open top into which a soft no. 9 rubber stopper is tightly fitted. Two glass tubes extending through the stopper into the bell jar connect the apparatus, one with an air pump and the other with bottles containing absorbing reagents for CO_2 or any other gas to be measured during the gaseous exchange that takes place in the soil or plants.

The construction of the apparatus is comparatively simple and does not occupy much time. The lower bell jar is first filled with soil to a depth of 8 inches and inserted into the pot. The soil is then brought up to its optimum moisture content and seeds are planted. A rubber band, 3½ inches wide and 5 inches in diameter, cut from an automobile tire-tube, is slipped onto the upper bell jar and then connected to the lower one. The rubber band seams the two bell jars and adheres to the glass so tightly that it would require considerable force to pull it off. The rubber stopper is then inserted and connected with the air pump and absorbing reagents. If the rubber band is not defective the apparatus should now be air-tight, as verified by a number of tests in this laboratory.

Before being admitted to the plant chamber, the air from the pump is first freed of carbon dioxide and moisture by being passed successively through concentrated solutions of KOH and H_2SO_4. Introduction of moisture into the chamber should be avoided because it increases the vapor pressure to such an extent as to interfere considerably with plant growth. After leaving the plant chamber, the air current passes through a bottle containing a standard solution of $Ba(OH)_2$ to absorb the CO_2 produced. The amount of CO_2 absorbed is determined by changing the reagent bottles and titrating with a standard weak acid. During this process the chamber should be disconnected from the pump by a pinchcock, or else the open glass tube momentarily released from the reagent bottle will draw all the air from the pump as well as from the other chambers, introducing new errors. In order to insure thorough air circulation, the tube connecting the apparatus to the pump should reach down to about two inches from the soil level while the tube leading the air out should extend only one or two inches from the top of the upper bell jar.

One of the methods employed in testing the apparatus was to carry over a known amount of ammonia by an air current into standard acid. For this purpose 150 cc. of a standard solution of NH_4OH, equivalent to 25 mgm. of NH_3, was poured into the apparatus and the top bell jar quickly closed with the rubber stopper. A glass tube, dipping into the solution and passing through the stopper, was connected to the pump. A continuous current of air was then circulated through the apparatus. The ammonia thus driven over was absorbed in reagent bottles containing measured quantities of H_2SO_4 in which the excess acid was then titrated. From the results presented in table 1 it will be seen that practically all the ammonia was recovered, provided that the aeration was continued sufficiently long. Due to the large volume (12,000 cc.) of the inside of the apparatus, 24 hours of continuous aeration was necessary

in order to drive over all the ammonia into the acid. Air pressure proved to be more efficient than suction, since nearly all the ammonia was recovered after 10 hours' aeration by the latter method, as is shown in the table, while 24 hours were required when the former method was used.

These two methods prove that the apparatus is air-tight, as neither under suction nor under air pressure was an appreciable loss of ammonia gas encountered.

In order to study the composition of soil gases, a long glass tube is dipped through the rubber stopper into the soil and connected by capillary tubing to a mercury pump or directly to a Haldane gas apparatus (2). Samples of soil air are withdrawn from time to time and analyzed. When not connected to the apparatus the glass tube must be kept closed by a pinchcock to prevent the inflow of outside air. In a similar manner samples of air on the surface of the soil are withdrawn from the apparatus for analysis.

Several respiration apparatuses can be connected to one pump by a series

TABLE 1

Data obtained in testing the apparatus by ammonia aeration

TEST NUMBER	SUCTION PUMP			AIR PRESSURE PUMP		
	NH_3 added	Time of aeration	NH_3 recovered	NH_3 added	Time of aeration	NH_3 recovered
	mgm.	*hours*	*mgm.*	*mgm.*	*hours*	*mgm.*
1	25	10	17.4	25	10	23.2
2	25	10	19.2	25	10	21.8
3	25	10	16.7	25	10	22.3
4	25	24	24.8	25	24	24.7
5	25	24	24.6	25	24	24.5
6	25	24	24.8	25	24	24.7

of pinchcocks and T-tubes without interfering with one another. Each plant chamber remains a separate unit and can be detached from the entire system without stopping the air current. Plate 1 shows two connected chambers in which Japanese millet was grown to maturity. The air pressure pump in this greenhouse, improvised by Allison (1), is especially fitted for this work as it maintains a slow but constant air circulation.

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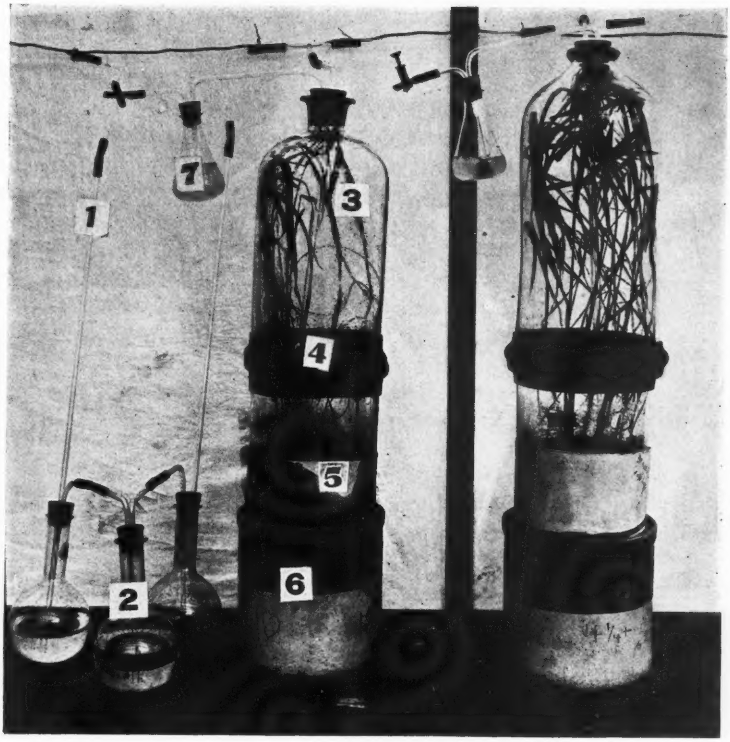
PLATE I

Showing Two Respiration Apparatuses Connected to One Pump

1, tube leading to pump; *2*, bottles containing absorbing solutions; *3*, upper bell jar; *4*, rubber band; *5*, lower bell jar; *6*, pot filled with sand to hold the apparatus; *7*, reagent to absorb the gases produced.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BIOCHEMICAL EFFECTS OF GYPSUM ON IOWA SOILS[1]

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INTRODUCTION

Since recent investigations have established the importance of sulfur in soil fertility, renewed attention is being directed to the use of gypsum as a fertilizer. Relatively large amounts of sulfur are removed from the soil by crops and by drainage water, while the quantities returned in the precipitation are generally insufficient to maintain the supply. Thus it is only a matter of time until sulfur becomes a limiting plant-food element just as is so often the case with nitrogen, phosphorus, and potassium.

Sulfur is essential to the growth of all organisms, and since the soil is the ultimate source of this element, the maintenance of a supply readily available to crops is of great importance. On many soils in various sections of the United States and in other countries, sulfur has already become a limiting factor in crop production, and fertilizers carrying it must be employed to obtain maximum yields.

Gypsum is a mineral containing sulfur in a form directly available to plants, and since it is readily obtained from numerous large deposits, investigations concerning its use as a fertilizer may be economically warranted.

A review of the literature on gypsum as affecting soils and crops shows that results obtained by different investigators are often dissimilar if not contradictory. Such discrepancies concerning the effects of gypsum on soil potassium are discussed by Lipman and Gericke (11), who attribute the lack of uniformity in results to variations in the mineral nature of soils from different localities. These variations may also affect the results of experiments dealing with the action of gypsum on soil phosphorus or other elements. Other soil conditions are also subject to variation, and may be no less important in determining the effects of any particular treatment on the chemical, physical, or biological properties of the soil. Among these may be included climate and

[1] Part of a thesis submitted to the graduate faculty of the Iowa State College in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

[2] The writer acknowledges with pleasure his indebtedness to the Gypsum Industries Association, of Chicago, whose fellowship made this investigation possible; to Dr. P. E. Brown for suggestions given concerning the work and the manuscript; and to Drs. Paul Emerson, L. W. Erdman, and H. J. Harper for suggestions and assistance given during the course of the work.

drainage, which affect moisture; texture; organic matter and even color. The soil type, in other words, is a determining factor and must be considered the least common denominator in interpreting results.

The following work was carried out along two lines: first, laboratory and greenhouse experiments with different crops and a single soil type to determine whether or not any correlation exists between crop response and chemical and biological changes induced in the soil by gypsum; and second, field experiments on various soil types in different sections of Iowa to determine the effects of gypsum on crop growth and composition under actual farming conditions.

PART I

Biochemical effects of gypsum on a soil under greenhouse conditions

Beneficial effects following the addition of gypsum to soils may result from the plant-food added, from influence on the microbiological processes of the soil, or from increased solubility of certain soil constituents. To study the action of gypsum on a soil in relation to crops produced, the following greenhouse experiment was conducted.

Plan of the experiment

The soil used was Miami silt loam, containing 550 p.p.m. of sulfur, 440 p.p.m. of phosphorus and 1180 p.p.m. of nitrogen. It had a lime requirement, as shown by the Tacke method, of 650 pounds per acre.

Four-gallon glazed pots, without drainage, served as containers. Four series of 14 pots each were arranged in duplicate, making a total of 112 pots. One series was kept fallow while the other three were seeded to alfalfa, red clover or soybeans.

The treatments used were as follows:

POT NUMBER	TREATMENT—POUNDS PER ACRE
1	Check
2	Gypsum—50
3	Gypsum—100
4	Gypsum—500
5	Sulfur—93 (equivalent to 500 pounds of gypsum)
6	Limestone—650
7	Rock phosphate—300
8	Sulfur—93 + limestone—650
9	Sulfur—93 + rock phosphate—300
10	Sulfur—93 + rock phosphate—300 + limestone—650
11	Gypsum—500 + rock phosphate—300
12	Gypsum—50 + limestone—650
13	Gypsum—100 + limestone—650
14	Gypsum—500 + limestone—650

The amounts of gypsum (93.7 per cent) used were those commonly employed in the field. Sulfur (99.6 per cent) was applied in an amount equivalent to the sulfur in the largest application of gypsum. Rock phosphate (73.8 per cent) was added in the proper amount to react with the sulfur used. A high grade dolomitic limestone was employed.

After the various materials were thoroughly mixed with the soil in the pots, the moisture content was brought to the optimum and kept there by adding water at regular intervals to weight.

Samples were taken from the fallow series on November 18, 1922, 3 weeks before the other series were seeded; 10 days later; and monthly thereafter for 8 months, a final sampling being made 14 months after the first. In all 11 samplings were made, which were tested for numbers of bacteria, numbers of actinomycetes, numbers of fungi, nitrifying power, sulfur-oxidizing power, soluble sulfates and lime requirement. Nitrate nitrogen determinations were run on the last set of samples.

The alfalfa and clover plants were thinned to 7 per pot. As soon as a series was uniformly in bloom the crop was harvested. Five cuttings of alfalfa and 3 of red clover were obtained. The roots were removed from the soil after the final cuttings were made, and soil samples were taken for analysis. The roots of all the plants were well inoculated with *Rhizobium*.

Because the soybean plants developed poorly during the winter they were discarded, and a new seeding and inoculation were made early in May. Leaves and pods were collected from the plants as they matured, the stalks being removed as soon as all the leaves had fallen. The roots at this time were so extensively decomposed that none could be obtained for analysis as originally planned. Soil samples were taken as in the other series.

After the dry weights of the various crops and roots were determined, the duplicates were combined and analyzed for total nitrogen. The soybean seed was analyzed separately from other portions of the plant.

Soil samples from duplicate pots were combined and determinations made on the composite samples as outlined for the fallow soils.

Analytical methods

The numbers of microörganisms in the soil were determined by the plate method, soil extract agar being used for bacteria and actinomycetes, and "synthetic" acid agar for fungi. The media were prepared according to the recommendations of Waksman and Fred (24).

The soil extract agar used for the first three samplings was prepared from an extract of a fertile black loam but the supply was then exhausted and for the latter work an extract was prepared from a sample of the same soil used in the greenhouse experiment. No marked difference in numbers of organisms due to the change in soil extract used was observed.

The usual method was followed in preparing dilutions, four plates being poured for each dilution. A dilution of 1:200,000 was used for bacteria and

actinomycetes, giving 25 to 50 colonies per plate. At the final sampling, the dilution was reduced one-half because of the small number of colonies.

A dilution of 1:20,000 was used for fungi. A dilution of 1:10,000 was also tried, but gave practically the same number of colonies per plate. Plates of 1:2000 dilution were also poured at the first and last sampling of the fallow pots and at the samplings of the cropped soils. These averaged 25 to 30 colonies per plate but spreaders and crowding of colonies caused much trouble.

The use of large petri dishes for counts of bacteria and actinomycetes was found to be advantageous, permitting development of colonies and facilitating differentiation between the two types of organisms. Many of the actinomycete colonies were about 1 cm. in diameter, and practically all could be differentiated without microscopic examination.

TABLE 1 †

Averages of all samplings on fallow pots

TREATMENT NUMBER	BACTERIA	ACTINOMYCETES	FUNGI	NITRIFYING POWER	SULFOFYING POWER	SOLUBLE SULFATES
	thousands	*thousands*	*thousands*	*per cent*	*per cent*	*p.p.m.*
1	2,822	4,066	152	19	27	45
2	2,876	4,040	138	15	27	62
3	2,909	4,104	133	20	25	47
4	2,600	3,886	124	19	27	78
5	3,297	4,434	123	18	43	72*
6	3,168	4,164	129	23	27	30
7	3,293	4,554	161	17	27	41
8	2,917	3,676	135	21	41	80
9	2,564	3,741	94	16	43	77
10	2,542	3,731	113	21	41	92
11	2,934	3,661	106	21	27	92
12	2,984	3,739	117	27	22	61
13	3,154	3,923	128	24	22	50
14	2,907	3,851	128	26	29	93

* Exclusive of last sampling.

† Data in all tables are expressed on anhydrous basis.

The data giving the numbers of organisms per gram of water-free soil at the various samplings are not given, the average results only being shown in table 1.

The nitrifying power of the soil was determined by the tumbler method with ammonium sulfate, incubating 6 weeks at room temperature and determining the percentage of ammonium sulfate oxidized. Nitrates were determined by the phenoldisulfonic acid method.

To obtain the sulfur-oxidizing power of the soil, 0.1 per cent of flour sulfur was mixed with the soil, brought to optimum moisture content and incubated for 10 days at room temperature. The amount of sulfur added converted to sulfates was then determined by the nephelometric method (19).

Lime requirements of the soils were determined by the Truog qualitative test.

Results obtained with fallow soils

Because the results obtained from the different samplings of the fallow pots were quite variable, only the averages given in table 1 are discussed.

Although the numbers of bacteria were occasionally increased by each of the various treatments, sulfur, limestone, and rock phosphate were most consistent in producing increases and show the largest increases in the average figures. Gypsum alone, and with limestone or rock phosphate, gave marked increases in several instances, the greatest effect being secured from the 100-pound application with limestone.

Very similar results were obtained with actinomycetes, except that the gypsum with limestone decreased the counts on the average, increases occurring in 13 out of 30 cases.

It is of interest to note that in nearly every case the number of actinomycetes exceeded the numbers of bacteria. This relationship also obtained in the air-dry stock sample and in frozen field soil taken from the place where the soil for the greenhouse experiment was secured. The numbers of organisms per gram of water-free soil are as follows:

SAMPLE (ALL TAKEN 1/28/24)	BACTERIA	ACTINOMYCETES	FUNGI
Untreated fallow soil	1,490,000	2,870,000	92,000
Original sample air-dry	400,000	600,000	30,000
Frozen field soil	3,900,000	5,260,000	300,000

The marked increase in numbers of actinomycetes found in the frozen soil suggests that if the increase in numbers of bacteria in frozen soils is due to the ascendency of a winter bacterial flora, then there is also a winter flora of actinomycetes.

Actinomycetes are usually considered to be less numerous than bacteria in soils. Conn (4) reports that in sod, where they are more abundant than in field soils, actinomycetes make up about 38 per cent of the colonies developing on gelatin plates. In a later publication (5) he states that ordinarily from 12 to 50 per cent of the colonies on plate cultures from soil are actinomycetes. Actinomycetes made up 4 to 46 per cent of the total flora found by Waksman and Curtis (23) in 25 soils obtained from widely different sources, the average being 17 per cent. Heavy soils and soils high in undecomposed organic matter usually contained the greatest numbers of these organisms. The actual numbers found averaged less than 1,000,000 per gram of soil. Martin (13) found that in many cases where green rye, oats, or buckwheat had been mixed with the soil the numbers of actinomycetes exceeded the numbers of bacteria.

Since the soil used in this experiment was neither heavy nor high in organic matter, the excess of actinomycetes over bacteria is the more unusual.

There was no consistent effect of the various treatments on the numbers of fungi. The number was always relatively high in the untreated soil. Rock phosphate gave a few pronounced increases, and is the only treatment showing an increase over the check in the average figures.

Nitrification of ammonium sulfate was increased by limestone and gypsum plus limestone, but gypsum alone increased it in only a few instances. The amounts of nitrates present at the last sampling were greatest in the soils which received rock phosphate.

The sulfur-oxidizing efficiency of the soil was markedly increased by sulfur. This is evident not only where sulfur was used alone, but also where it was combined with limestone or rock phosphate. Gypsum, limestone, rock phosphate, and various combinations of these had practically no effect on sulfur oxidation.

Distinct increases in the amounts of soluble sulfates were found in all soils treated with the largest amount of gypsum, whether alone or with limestone or rock phosphate. Several weeks after the first sampling, increased amounts of sulfates were found in all soils which had received sulfur. These increases persisted. The amounts of sulfates in all the soils tended to increase with time, reaching a maximum in early summer and then decreasing slightly.

The percentage of nitrogen in the soil increased in all pots during the experiment. In no case, however, did any treatment produce more fixation than occurred in the untreated soil. The data are not given.

While differences in results obtained at each sampling were often of considerable magnitude, differences between averages of all samplings are greatly reduced. In a general way, however, the differences between the averages are in the same order, and the same conclusions are reached as would be obtained by considering all the data from the individual samplings.

The fallow soils were analyzed for water-soluble phosphorus at the last sampling. No phosphorus was detected in water extracts of any of the variously treated soils.

Results obtained on cropped soils

The results obtained on the cropped soils are given in table 2.

Alfalfa series. In the alfalfa series, only one of the treatments increased the number of bacteria over the number found in the check soil. Decreases were particularly marked in the soils treated with sulfur, sulfur plus rock phosphate, sulfur plus rock phosphate and limestone, gypsum at the rate of 500 pounds per acre plus rock phosphate, and gypsum at the rate of 100 pounds plus limestone. The numbers of actinomycetes were decreased in the same soils and also where 500 pounds of gypsum plus limestone was used but were increased in the soils receiving gypsum at the rate of 100 pounds per acre, limestone, rock phosphate, and gypsum at the rate of 50 pounds per acre plus limestone. In only one instance was the number of fungi increased, this being where rock phosphate was added.

TABLE 2

Microörganisms, nitrification, sulfofication and sulfates in cropped soils

POT NUMBER	BACTERIA			ACTINOMYCETES			FUNGI			NITRIFICATION $(NH_4)_2SO_4$ NITRIFIED			SULFOFICATION SULFUR OXIDIZED			SULFUR AS SULFATES		
	Alfalfa	Red clover	Soy-beans	Alfalfa	Red clover	Soy-beans	Alfalfa	Red clover	Soy-beans	Alfalfa	Red clover	Soy-beans	Alfalfa	Red clover	Soy-beans	Alfalfa	Red clover	Soy-beans
	thousands	*thousands*	*thousands*	*thousands*	*thousands*	*thousands*	*thousands*	*thousands*	*thousands*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*p.p.m.*	*p.p.m.*	*p.p.m.*
1	2,480	1,850	1,270	3,730	2,460	2,120	124	82	64	22	34	4	15	35	23	74	161	271
2	2,280	1,440	1,900	3,930	2,870	3,380	104	103	127	28	36	8	14	24	21	41	84	130
3	2,480	1,650	1,910	4,350	2,470	2,970	104	82	127	27	34	7	11	18	15	69	116	96
4	2,070	1,650	1,280	3,930	2,470	4,920	124	62	86	30	34	8	17	19	12	77	160	64
5	1,860	1,240	1,280	3,310	2,470	3,620	124	82	85	28	41	8	24	42	33	67	154	78
6	2,470	1,850	3,640	4,530	3,090	4,920	124	82	107	32	36	13	11	18	13	28	88	44
7	2,470	1,650	.....	4,740	3,910	3,640	144	103	128	25	33	12	8	23	13	26	111	54
8	2,070	2,270	1,704	3,730	2,880	4,470	62	82	128	30	34	11	25	46	23	63	116	73
9	1,440	2,060	2,980	3,300	3,090	4,690	62	82	149	26	37	4	21	44	22	71	134	98
10	1,850	2,470	2,140	3,090	3,910	3,640	103	124	128	40	37	6	30	36	25	64	108	81
11	1,660	2,270	2,770	2,690	2,880	4,050	83	82	85	32	36	6	16	22	17	78	152	73
12	2,910	1,660	3,210	4,160	2,280	4,920	104	62	86	48	41	5	18	20	7	41	112	61
13	1,040	1,850	4,050	2,480	2,670	6,180	83	144	128	47	37	7	15	19	10	50	84	45
14	2,070	1,640	2,980	2,690	2,260	5,540	83	103	85	46	38	5	17	20	12	61	130	55

The nitrifying power was appreciably higher in the soils receiving lime, and gypsum plus lime. The sulfofying power was increased in all soils treated with sulfur, either alone or in combination with limestone or rock phosphate.

Water-soluble sulfates were most abundant in the soils treated with sulfur, and with the largest amount of gypsum. The untreated soil also was high in sulfates. Nitrates were absent in all the soils. This is not unusual in view of the fact that a vigorously growing crop was present on the soil up to the time of sampling.

Red clover series. Soils of the red clover series treated with sulfur plus limestone, sulfur plus rock phosphate and limestone, and gypsum at the rate of 500 pounds per acre plus rock phosphate, contained more bacteria and actinomycetes than did the untreated soil. More actinomycetes were also present in the limed and rock phosphate treated soils, except for the limed plots with 50 pounds and 500 pounds of gypsum. Gypsum alone at the rate of 50 pounds gave an increase. Fungi were most numerous in the soils treated with gypsum at the rate of 50 pounds per acre, rock phosphate, sulfur plus rock phosphate and limestone, and gypsum at the rates of 100 and 500 pounds per acre plus limestone.

The nitrifying power of the differently treated soils varied but little. Slight increases occurred in the soils receiving sulfur alone and with rock phosphate and with the rock plus limestone, and the smallest application of gypsum plus limestone. The sulfofying power was greatest in the soils treated with sulfur, either alone or combined with limestone or rock phosphate. It was decreased under the other treatments.

Sulfates were most abundant in the untreated soil, and in the soils receiving sulfur and the largest application of gypsum. No increases were secured for the other treatments. Small quantities of nitrates were found in all the soils.

Soybean series. All treated soils in the soybean series contained more bacteria, actinomycetes, and fungi than did the check. Limestone, and gypsum plus limestone gave especially large increases, except in the case of the fungi.

The nitrifying power was comparatively low in all cases, but appreciable increases were found in the soils receiving limestone, rock phosphate, and sulfur plus limestone. The only marked increase in sulfofying power was in the sulfur-treated soil. The check soil and the soil receiving the smallest application of gypsum were notably high in soluble sulfates. Small amounts of nitrates were present in all the soils.

Crop yields and nitrogen content

Alfalfa series. The total yield of the five alfalfa crops each of which was harvested, weighed and analyzed separately is given in table 3 together with the weight and nitrogen content of the roots. The yields of alfalfa were considerably increased by the largest application of gypsum alone, the smallest

application of gypsum plus limestone, sulfur, sulfur plus limestone, and sulfur plus limestone and rock phosphate. Limestone alone had practically no effect. Rock phosphate, and smaller applications of gypsum gave only slight

TABLE 3

Alfalfa

TREATMENT NUMBER	TOTAL OF 5 CROPS			ROOTS		
	Weight	Nitrogen content		Weight	Nitrogen content	
	gm.	*per cent*	*mgm.*	*gm.*	*per cent*	*mgm.*
1	141.6	2.7	3,840	45	1.9	885
2	148.1	2.9	4,289	56	1.9	1,064
3	148.9	2.9	4,305	46	1.8	828
4	176.3	2.9	5,103	52	1.8	936
5	175.4	2.8	4,896	50	1.7	850
6	142.3	2.8	3,981	44	1.8	792
7	153.8	2.7	4,168	44	1.8	792
8	184.0	2.7	5,008	54	1.8	972
9	160.0	2.7	4,358	43	1.8	774
10	176.0	2.8	4,840	42	1.8	756
11	161.6	2.7	4,389	42	1.8	756
12	175.4	2.8	4,836	46	1.8	828
13	164.6	2.8	4,688	57	1.9	1,083
14	147.0	2.9	4,208	42	1.7	714

TABLE 4

Red Clover

TREATMENT NUMBER	TOTAL OF 3 CROPS			ROOTS		
	Weight	Nitrogen content		Weight	Nitrogen content	
	gm.	*per cent*	*mgm.*	*gm.*	*per cent*	*mgm.*
1	167.4	2.5	4,214	20	2.5	500
2	150.6	2.4	3,685	17	2.3	391
3	173.0	2.4	4,148	20	2.2	440
4	179.6	2.5	4,501	25	2.3	575
5	156.5	2.4	3,798	21	2.2	462
6	158.8	2.4	3,826	16	2.2	352
7	156.5	2.5	3,854	17	2.4	408
8	139.8	2.5	3,533	11	2.3	253
9	163.0	2.5	4,067	16	2.1	336
10	146.7	2.6	3,777	14	2.3	322
11	150.9	2.5	3,788	11	2.5	275
12	155.7	2.6	4,040	11	2.3	253
13	145.2	2.6	3,750	11	2.5	275
14	145.5	2.6	3,770	14	2.6	364

increases. While the smallest amount of gypsum in combination with the limestone gave a marked increase in yield, the larger quantities with limestone gave much smaller increases.

Gypsum alone in all amounts and gypsum at the rate of 500 pounds per acre plus limestone gave small increases in nitrogen percentage in the crop.

Root development was visibly increased by gypsum at 50 and 500 pounds per acre, by gypsum at the rate of 100 pounds per acre plus limestone, by sulfur, and by sulfur plus limestone. The percentage of nitrogen in the roots and in the soil was not increased over the percentage in the check by any of the treatments; in a few cases slight decreases were found.

Red clover series. The red clover yields as given in table 4, showing the total of three crops, were not greatly increased by any of the various treatments. The soils receiving gypsum alone at the rate of 100 and 500 pounds per acre yielded more than the check at each cutting. All other treatments decreased the total crop. Increases were given by sulfur, limestone, and rock phosphate at the second cutting but these do not show in the total.

TABLE 5

Soybeans

TREATMENT NUMBER	TOTAL CROP HAY + SEED		
	Weight	Nitrogen content	
	gm.	*mgm.*	*per cent*
1	196.5	5,599	2.8
2	170.5	4,657	2.7
3	221.9	6,695	3.0
4	207.9	6,184	3.0
5	191.3	5,247	2.7
6	203.1	5,774	2.8
7	196.6	5,629	2.9
8	209.6	6,282	3.0
9	216.0	6,230	2.9
10	197.4	5,926	3.0
11	183.8	5,640	3.1
12	190.2	5,844	3.1
13	195.5	6,193	3.2
14	179.4	5,346	3.0

The percentage of nitrogen in the clover decreased with succeeding crops. Variations due to the different treatments were not distinct until the last cutting, at which time the plants from soil treated with gypsum in all amounts plus limestone, and sulfur plus limestone, contained appreciably more nitrogen than did plants from any of the other pots. These results are indicated in the totals.

Root development was increased in the soil receiving gypsum at the rate of 500 pounds per acre. The percentage of nitrogen in the roots varied widely, but there is no apparent correlation between this and the different treatments. The nitrogen content of the soil was maintained in all cases, and where gypsum at the rates of 100 and 500 pounds per acre was applied very slight increases were noted.

Soybean series. The total yield of soybeans, hay plus seed, with the nitrogen content is given in table 5. Increases in yield were given by gypsum at the rate of 100 and 500 pounds per acre, and by sulfur plus limestone and plus rock phosphate, and by limestone alone. Considering seed only, sulfur plus rock phosphate, gypsum at the rate of 100 pounds per acre plus limestone, and gypsum alone at the rate of 100 pounds per acre gave the largest yields, little variation existing between these.

The hay and seed varied only slightly in percentage of nitrogen. Considering the crop as a whole, slightly higher percentages of nitrogen were found on several of the treated soils. The nitrogen content of the soil, including roots, was not greatly altered.

The effect of sulfur oxidation on nitrate accumulation

The effect of sulfur oxidation on the accumulation of nitrates in soil under laboratory conditions was studied by determining the amounts of nitrate nitrogen produced in soil samples to which sulfur had been added for sulfofication tests. Data obtained with soil from each of the cropped series and from the last sampling of the fallow series are presented in tables 6 to 9.

The results show that nitrates may accumulate where sulfur is being oxidized. The nitrifying power of the soil as determined by the oxidation of ammonium sulfate, the amount of sulfur oxidized and the amount of sulfate sulfur originally present in the soil do not appear to influence formation of nitrates under the conditions of this experiment. A similar generalization holds for the amount of nitrates originally present in the soil, although it is of interest to note that in the alfalfa series where nitrates were absent from the soil at the beginning of the incubation period, more nitrates accumulated where sulfur was oxidized than in the checks. In the fallow soils, where comparatively large quantities of nitrates were present when the experiment was started, large fluctuations in the amounts of nitrates accumulating in the different samples were found. These cannot be correlated with the different treatments of the soils.

It is a generally accepted opinion that nitrate formation is seriously depressed under conditions of soil acidity, although the experimental evidence is conflicting. Since sulfur oxidation is accompanied by an increase in soil acidity, the main interest in this brief experiment lies in the fact that in a short time nitrates increased in several soils where relatively large amounts of sulfur were oxidized.

Ames and Richmond (2) found that oxidation of sulfur in soils not well supplied with bases depressed the activities of nitrifying organisms. Lipman, et al. (12), on the other hand, found that nitrification is not necessarily inhibited by a highly acid condition of the soil brought about by oxidation of large amounts of sulfur.

The kind of nitrifiable material present in the soil may determine to some extent the effect of sulfur oxidation on nitrification. This is suggested by the

TABLE 6

Effect of sulfur oxidation on nitrate accumulation

Fallow series—last sampling

POT NUMBER	AT TIME OF SAMPLING		AFTER 10 DAYS INCUBATION				NITRIFYING POWER
	N as NO_3	S as SO_4	S oxidized	N as NO_3 in checks	N as NO_3 in S treated soil	Increase in N as NO_3 in S treated soil	
	p.p.m.	*p.p.m.*	*per cent*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*per cent*
1	44	77	11	57	57	0	17
2	53	143	10	87	87	0	15
3	37	85	10	96	57	−39	11
4	36	65	10	53	46	−7	27
5	44	2,388	21	57	80	23	30
6	48	64	13	57	64	7	11
7	64	93	6	69	87	21	−4
8	42	124	16	69	46	−23	28
9	61	111	25	60	87	27	5
10	75	155	19	102	64	−38	9
11	71	135	7	69	46	−23	20
12	29	81	5	64	38	−26	25
13	23	72	8	64	64	0	18
14	47	80	3	80	69	−21	5

TABLE 7

The effect of sulfur oxidation on nitrate accumulation

Alfalfa series

POT NUMBER	AT TIME OF SAMPLING		AFTER 10 DAYS INCUBATION				NITRIFYING POWER
	N as NO_3	S as SO_4	S oxidized	N as NO_3 in checks	N as NO_3 in S treated soil	Increase in N as NO_3 in S treated soil	
	p.p.m.	*p.p.m.*	*per cent*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*per cent*
1	None	74	15	2	3	1	22
2	None	41	14	2	4	2	28
3	None	69	11	2	4	2	27
4	None	77	17	2	5	3	30
5	None	67	24	1	4	3	28
6	None	28	11	3	4	1	32
7	None	26	8	2	3	1	25
8	None	23	25	0	4	4	30
9	None	71	21	0	5	5	26
10	None	64	30	0	4	4	40
11	None	78	16	2	5	3	32
12	None	41	18	2	5	3	48
13	None	50	15	2	5	3	47
14	None	61	17	1	4	3	46

TABLE 8

The effect of sulfur oxidation on nitrate accumulation

Red clover series

POT NUMBER	AT TIME OF SAMPLING		AFTER 10 DAYS INCUBATION				NITRIFYING POWER
	N as NO_3	S as SO_4	S oxidized	N as NO_3 in checks	N as NO_3 in S treated soil	Increase in N as NO_3 in S treated soil	
	p.p.m.	*p.p.m.*	*per cent*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*per cent*
1	3	161	35	8	5	−3	34
2	4	84	24	8	6	−2	36
3	4	116	18	8	5	−3	34
4	4	160	19	9	6	−3	34
5	4	154	42	8	4	−4	41
6	4	88	18	8	7	−1	36
7	4	111	23	7	5	−2	33
8	4	116	46	7	0	−7	34
9	4	134	44	8	0	−8	37
10	5	108	36	8	0	−8	37
11	4	152	22	7	5	−2	36
12	3	112	20	6	5	−1	41
13	4	84	19	7	5	−2	37
14	4	130	20	8	6	−2	38

TABLE 9

The effect of sulfur oxidation on nitrate accumulation

Soybean series

POT NUMBER	AT TIME OF SAMPLING		AFTER 10 DAYS INCUBATION				NITRIFYING POWER
	N as NO_3	S as SO_4	S oxidized	N as NO_3 in checks	N as NO_3 in S treated soil	Increase in N as NO_3 in S treated soil	
	p.p.m.	*p.p.m.*	*per cent*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*per cent*
1	4	271	23	6	3	−3	4
2	3	130	21	6	3	−3	8
3	5	96	15	7	4	−3	7
4	5	64	12	9	6	−3	8
5	4	78	33	6	2	−4	8
6	4	44	13	6	5	−1	13
7	4	54	13	6	6	0	12
8	4	73	23	7	4	−3	11
9	7	98	22	6	4	−2	4
10	5	81	25	8	5	−3	6
11	5	73	17	6	5	−1	6
12	5	61	7	10	9	−1	5
13	4	45	10	7	6	−1	7
14	4	55	12	7	4	−3	5

results obtained with soils of the different cropped series. Thus with soil containing residues from alfalfa roots, sulfur oxidation appeared to enhance nitrification, while in soils containing residues of red clover or soybean roots it exerted a contrary effect.

Summary and discussion of results

Numbers of bacteria were most consistently increased by sulfur, limestone, and rock phosphate treatments. The increases due to limestone and rock phosphate accord with general experience. Rudolfs (17) found that small applications of sulfur to a sandy loam slightly increased the numbers of bacteria developing on agar plates while amounts in excess of 1000 pounds per acre had a marked depressing effect. Pitz (14) concluded that small amounts of sulfur had little effect on bacterial numbers.

Rock phosphate and sulfur were most effective in increasing the numbers of actinomycetes. Rock phosphate also tended to increase the numbers of fungi. The assimilation of rock phosphate by members of these two groups of microorganisms may be an important factor in its availability under field conditions. The total mass of actinomycetes in the average soil is much in excess of the bacterial substance present (18), and may comprise a considerable amount of material. Since rock phosphate stimulated development of these organisms, it was undoubtedly assimilated extensively. The assimilated phosphorus in such cases may readily become available to higher plants, as it has been shown (22) that fungous material is readily mineralized.

The most persistent and outstanding feature in this experiment is the stimulating effect of sulfur on sulfur oxidation. Sulfur alone or in combination with other substances extensively increased the sulfur-oxidizing efficiency of the soil. This was evident at each sampling of the fallow series and in each of the cropped series.

The tendency of sulfur applications to increase the sulfur-oxidizing power of soils in the field has been pointed out in a previous publication (8). Since sulfur is a synergic food for sulfur-oxidizing organisms, its effect in increasing the sulfofying power of a soil is easily explained on the basis that it increases either the physiological efficiency or the number of these organisms, or both. Gypsum, being completely oxidized, cannot exert the same effect. In this experiment it was found to have practically no effect on sulfofication. Brown and Kellogg (3), on the other hand, found that gypsum at the rate of 1000 pounds per acre increased the sulfofying power of a loam. Possibly the effect of gypsum on sulfur oxidation is indirectly due to effects on aeration and moisture-holding capacity of the soil.

The amounts of water-soluble sulfates found in all the soils were comparatively large. In the fallow soils an increase in sulfates was observed during the spring and summer months, probably due to increasing sulfofication with rising temperature. As would be expected, the largest amounts of sulfates were found in the soils treated with sulfur and with the largest application of

gypsum, but at no time were enough sulfates found to account for all the sulfur added. Since the pots were not provided with drainage, no sulfates were lost by leaching; apparently, appreciable quantities were assimilated and held by the soil microflora.

An exceedingly large amount of sulfates found in the sulfur-treated fallow soil at the close of the experiment cannot be accounted for. It is of interest to compare the various data for this soil with those obtained for the other soils at the same sampling. Thus, while the numbers of bacteria and actinomycetes were greatly reduced, the number of fungi was considerably higher than in any of the other soils. This naturally followed from the high acidity of the soil; the Truog test indicated a lime requirement of over four tons, while the hydrogen electrode showed the pH of the soil to be 3.23. The untreated soil showed a lime requirement of less than one ton and a pH of 5.55. Thus there is every indication that an excessive quantity of sulfur had been oxidized in the sulfur-treated soil.

Not only were fungi more abundant in this soil, but of the total number of colonies developing on the plates, nearly all were *Penicillium luteum*. On plates of the other soils this organism was rarely encountered. Its abundance in the sulfur-treated soil was therefore significant, especially since it has been found that *Penicillium luteum* can oxidize sulfur in soil (1). Pure cultures of this organism were obtained from the plates, and flasks containing free sulfur and a nutrient solution of dextrose, potassium sulfocyanide, and mineral nutrients were inoculated from these. After 8 weeks' incubation at room temperature, qualitative tests showed that the fungus had oxidized considerable amounts of sulfur.

Another significant point is that this highly acid soil possessed not only the highest sulfofying power but also the greatest nitrifying power of the series. A relatively large quantity of nitrates was also present. This provides a basis for speculation on the possibility of *Penicillium luteum* being a nitrifying as well as a sulfofying organism.

The cropped soils were found to be particularly high in soluble sulfates. This is in marked contrast to the amounts of nitrates found. While more nitrates were found in the fallow soils, even here sulfates were in excess. The same relation was found in field soils, sulfates being relatively abundant while nitrates were frequently absent. In spite of this condition sulfur and sulfates have increased crop yields in the field as well as in the greenhouse. Since crops use nitrates much more extensively than sulfates, the relative excess of the latter over nitrates is not contrary to expectation. It is significant, however, that while appreciable quantities of sulfates may be present in a soil, the addition of further amounts may increase crop growth. Apparently it is not an absolute lack of sulfates, but the lack of a sufficiently high concentration of sulfates in the soil that tends to limit crop growth.

According to the Truog test, none of the various treatments had a noticeable effect on the lime requirements of the fallow soils. These remained

uniformly less than one ton during the entire course of the experiment, except for the noteworthy increase found in the sulfur-treated soil at the last sampling. The lime requirements of the cropped soils also were found to be practically unaltered.

Crop yields in the greenhouse were increased by gypsum and sulfur. These materials were particularly favorable to the development of alfalfa. In general, the larger applications of gypsum were most effective, not only in increasing yields but also in increasing the percentage of nitrogen in the crop. Since gypsum exerted but little effect on nitrification and on fixation of nitrogen by the soil, the increased nitrogen content of the crops must have been due to a favorable effect of gypsum on the symbiotic nitrogen fixation.

The results as a whole indicate that in this investigation gypsum increased crop growth by acting directly as a sulfur fertilizer.

Conclusions

1. Gypsum had practically no effect on the numbers of soil microörganisms developing on agar plates.
2. Gypsum exerted no effect on nitrification or on sulfofication.
3. Gypsum did not affect the lime requirement of the soil.
4. Sulfur markedly increased the sulfofying power of the soil.
5. Crop growth, particularly in the case of alfalfa, was materially increased by gypsum and by sulfur. The largest application of gypsum was more effective than the smaller ones. Sulfur in a quantity equivalent to the largest application of gypsum gave essentially the same results as gypsum.
6. Under the conditions of this experiment gypsum acted largely as a direct sulfur fertilizer.

PART II

Field experiments with gypsum

To determine the effects of gypsum on crops under field conditions, coöperative experiments on several representative soil types were conducted in various sections of Iowa. Four of these experiments were placed on alfalfa fields, two of which were old stands. A fifth test was made on a field seeded to oats and clover.

A series of $\frac{1}{10}$-acre plots was laid out on each field, and gypsum was applied at the rates of 50, 150, 300, and 500 pounds per acre. On two of the fields an additional plot was treated with sulfur at the rate of 100 pounds per acre. In one series limestone was applied to half of each plot; in each of the other experiments limestone had previously been applied to the entire field. A central plot was left as a check in all cases.

Yields were determined from cuttings made on areas 5 feet square selected on representative parts of the plots. Three such areas were cut on each plot, except in the series having half of each plot limed, where two areas were cut

from each half. Samples of the crop and of the soil were taken wherever a cutting was made, different samples from the same plot being combined. The crops were analyzed for total nitrogen by the Kjeldahl method. The soils were tested for lime requirement by the Iowa soil acidity test (6) and the Soiltex method (20, 21), and, in some cases, for soluble sulfates and nitrates by the nephelometric (19) and phenoldisulfonic acid methods respectively. Yields of hay per acre were calculated on the air-dry basis.

Grand Mound field

This experiment was located on Carrington fine sand, a soil of a minor type selected because of the difficulty it usually presents to the establishment of a stand of alfalfa. The field had previously been in meadow, corn, and oats. It was manured, limed, and seeded to alfalfa late in the summer of 1922. Two months later, when the gypsum was applied, the stand was well distributed but not uniform, due probably to variations in hardness of the seed.

TABLE 10

Grand Mound field

Alfalfa—Carrington fine sand

PLOT NUMBER	TREATMENT PER ACRE	ALFALFA HAY CUT 6/20/23			SOIL			
		Yield per acre	Nitrogen content per acre		S as SO_4	N as NO_3	Lime requirement Iowa test	Soiltex
	pounds	*pounds*	*per cent*	*pounds*	*p.p.m.*	*p.p.m.*	*tons*	*pH*
1	Gypsum 500	3,000	2.0	60	20	3	1½	5.5
2	Gypsum 300	3,800	2.2	84	20	5	1	5.5
3	Check	2,450	2.4	59	15	3	1	5.5
4	Gypsum 150	3,000	2.3	69	13	2	1	5.5
5	Gypsum 50	4,400	2.4	106	16	4	1½	5.0

Spring drouths hindered development of the crop, and when the samples were taken the stand was decidedly weedy and spotty except on the plot receiving gypsum at the rate of 50 pounds per acre.

From the data of table 10 it is apparent that gypsum produced increases in the yield of hay. In view of the unfavorable moisture conditions which obtained, it is possible that the effects noted may have been due in part to an influence of gypsum on the moisture relations of the soil or those of the plant. The lesser effect of the larger applications may be attributed to the fact that these plots were on a higher level and therefore sooner became deficient in moisture.

The analyses for total nitrogen show that the percentage of nitrogen in hay from all the plots was below average. This was probably due to the poor inoculation; only occasional nodules could be found on the roots at the time samples were taken.

Since growth of the crop on the check plot was much more retarded than on any of the others, the higher nitrogen content found in this case is in accordance with general experience. It is significant that the percentage of nitrogen in the hay from the plot giving the largest yield did not fall below that of the hay from the check plot. The small amount of gypsum applied not only materially increased the yield but also apparently increased the amount of nitrogen available to the crop.

Waverly field

An excellent 3-months-old stand of alfalfa was on the Waverly field when gypsum and limestone were applied, but due to winter injury and spring drouth a poor crop developed. As seen from the data in table 11, however, differences in yields apparently due to the different treatments were obtained. These differences were discernible in the field.

TABLE 11

Waverly Field

Alfalfa—Carrington loam

PLOT NUMBER	TREATMENT PER ACRE	ALFALFA HAY CUT 6/6/23			SOIL			
		Yield per acre	Nitrogen content per acre		S as SO_4	N as NO_3	Lime requirement Iowa test	Soiltex
	pounds	*pounds*	*per cent*	*pounds*	*p.p.m.*	*p.p.m.*	*tons*	*pH*
1	Gypsum 50	1,700	2.4	41	13	1*	1	5.5
2	Gypsum 150	2,700	2.6	70	13	1	1	5.5
3	Check	1,700	2.6	44	15	1	1	5.5
4	Gypsum 300	2,500	2.5	63	31	1	1	5.5
5	Gypsum 500	3,100	2.5	78	16	1	1	5.5
6	Gypsum 50 + limestone	1,500	2.5	38	14	1	1½	5.5
7	Gypsum 150 + limestone	1,700	2.8	48	23	1	1	5.5
8	Limestone	1,500	2.5	38	23	1	1	5.5
9	Gypsum 300 + limestone	1,700	2.6	44	20	1	1	5.5
10	Gypsum 500 + limestone	2,300	2.6	60	28	1	2	5.5

* Less than 1 p. p. m. in each plot.

The larger applications of gypsum increased the yields about 50 per cent, but the addition of limestone tended to decrease this effect.

The lack of variations in reaction of the soil of the various plots shows that not only gypsum but also the limestone applied had no noticeable effect. The lack of effect of the limestone may be ascribed to the low lime requirement of the soil, the coarseness of the limestone, and the limited moisture conditions.

Ames field no. 1

For investigations on the effect of gypsum on a well-established stand of alfalfa, a field on O'Neill sandy loam was secured at Ames. It was seeded to alfalfa in 1919 and reseeded the following year. Limestone applied in 1920 at the rate of 2 tons per acre gave good results. Sulfur and gypsum were applied April 10, 1923 to plots 43.5 by 100 feet.

TABLE 12

Ames field no. 1

Alfalfa (3-year-old stand)—O'Neill sandy loam

PLOT NUMBER	TREATMENT PER ACRE	ALFALFA HAY			SOIL			
		Yield per acre	Nitrogen content per acre		S as SO_4	N as NO_3	Lime requirement Iowa test	Soiltex
	pounds	*pounds*	*per cent*	*pounds*	*p.p.m.*	*p.p.m.*	*tons*	*pH*
			First crop, 6/18/23					
1	Sulfur 100	5,400	2.5	135	31	9	1	5.5
2	Gypsum 500	5,100	2.5	128	48	8	1	5.5
3	Gypsum 300	5,100	2.2	112	28	4	1	5.5
4	Check	4,300	2.4	103	15	4	1	5.5
5	Gypsum 150	5,400	2.3	124	20	12	1	5.5
6	Gypsum 50	5,600	2.4	134	39	8	1½	5.0
			Second crop, 8/2/23					
0	Check	950						
1	Sulfur 100	1,700	3.0	51	37	8	1	5.5
2	Gypsum 500	1,350	2.4	32	28	8	1	5.5
3	Gypsum 300	1,450	2.7	39	20	6	1	5.5
4	Check	1,100	2.5	28	33	20	1	5.5
5	Gypsum 150	950	2.6	25	37	10	1	5.5
6	Gypsum 50	1,050	2.8	29	23	8	1	5.5
7	Check	740						
			Total yield					
1	Sulfur 100	7,100	2.6	186				
2	Gypsum 500	6,450	2.5	160				
3	Gypsum 300	6,550	2.3	151				
4	Check	5,400	2.4	131				
5	Gypsum 150	6,350	2.3	149				
6	Gypsum 50	6,650	2.4	163				

From data presented in table 12 it is evident that for the first cutting all treatments gave an increase of about 20 per cent over the check. The smallest application of gypsum gave the largest increase. Gypsum at 150 pounds and sulfur at 100 pounds per acre gave somewhat smaller increases.

The second crop developed poorly because of dry weather. In order to

obtain the most accurate data possible the entire stand of each plot was cut and weighed, and an area at each end of the series was included for additional checks.

Results of the second cutting show that sulfur had the greatest effect, although the larger applications of gypsum also gave increases. The plots receiving the smaller applications were located near a slope with gravel outcrops and undoubtedly moisture became a limiting factor here. For this reason, the yield on the plot receiving gypsum at the rate of 50 pounds per acre is significant in indicating a possible value of gypsum in minimizing the effect of drouth.

The total yields for both cuttings show that the sulfur treatment gave an increase of nearly 1 ton over the check, while each of the different applications of gypsum gave an increase of approximately ½ ton.

TABLE 13

Ames field no. 2

Alfalfa (1-year-old stand)—Carrington loam

PLOT NUMBER	TREATMENT PER ACRE	TOTAL HAY CROP FROM 3 CUTTINGS			LIME REQUIREMENT PER ACRE AND pH OF SOIL			
		Yield per acre	Nitrogen content per acre		Start		End	
	pounds	*pounds*	*per cent*	*pounds*	*tons*	*pH*	*tons*	*pH*
0	Check	......	...	...	...	...	...	...
1	Sulfur 100	11,150	2.5	281	0.5	5.5	1.0	5.0
2	Gypsum 500	12,500	2.8	355	0.5	5.5	1.0	5.5
3	Gypsum 300	10,450	2.7	288	0.5	5.5	0.5	5.5
4	Check	9,450	2.7	259	0.5	5.5	1.0	5.5
5	Gypsum 150	9,450	2.8	266	0.5	5.5	0.5	5.5
6	Gypsum 50	9,850	2.7	263	0.5	5.5	1.0	5.5
7	Check	......	...	...	...	...	...	...

While the percentage of nitrogen in the hay from the various plots varied but slightly for the first crop, the plots receiving sulfur and the largest application of gypsum yielded hay containing the most nitrogen. At the second cutting all treatments except the 500-pound application of gypsum produced an increase in nitrogen content of the crop. This increase was especially pronounced on the plot receiving sulfur.

Ames field no. 2

The data given in table 13 were obtained from a stand of alfalfa seeded the previous year on Carrington loam. Three cuttings were made and at each the stand was excellent, being uniformly heavy and free from weeds. Only the total yield is given in the table.

Examination of the data reveals that in all cases the heaviest application of gypsum gave the most substantial increase, the total increase over the check being 1¼ tons. Sulfur increased the total yield 1 ton. Gypsum at the rate of

300 pounds per acre gave a total increase of ½ ton. The smaller applications gave slight increases at first but the effect fell off later, so that on comparing total yields there is practically no balance in their favor.

The percentage of nitrogen in the hay from all the plots increased with succeeding cuttings. At the same time the yields decreased. Marked variations in the nitrogen content of hay from the different plots were found. Hay from the sulfured plot contained the lowest percentage of nitrogen in all cases. The various gypsum treatments had no pronounced effect on the nitrogen content of the total crop yield.

Storm Lake field

The experiment with oats was placed on Carrington silt loam near Storm Lake. Plots 66 feet square were marked off on a level representative area of the field and treatments were applied April 28, 1923. The preceding week

TABLE 14

Storm Lake field—Carrington silt loam

PLOT NUMBER	OATS								SOIL			
	Treatment per acre	Straw per acre	Grain yield per acre		Total crop			N of total crop in grain	S as SO_4	N as NO_3	Lime requirement Iowa test	Soiltex
					Yield per acre	Nitrogen content per acre						
	lbs.	*lbs.*	*lbs.*	*bu.*	*lbs.*	*per cent*	*lbs.*	*per cent*	*p.p.m.*	*p.p.m.*	*tons*	*pH*
1	Gypsum 500	2,900	1,100	34	4,000	0.9	36	58	23	Trace	1.5	5.5
2	Gypsum 300	2,800	1,150	36	3,950	1.1	43	55	9	Trace	2.0	5.5
3	Check	1,900	1,100	34	3,000	1.1	33	69	3	Trace	2.0	5.5
4	Gypsum 150	2,500	1,400	44	3,900	1.1	43	68	13	Trace	2.0	5.5
5	Gypsum 50	2,600	1,350	42	3,950	1.1	44	61	6	Trace	2.0	5.5

following disking in of corn stubble, Green Russian oats and red clover were sown. Seed was sprouting when the gypsum was applied but no seedlings had broken through.

Samples were cut from the plots on July 23, about three days before the grain was mature. The stand was slightly uneven, particularly on the check plot, from which, therefore, two additional areas were cut when the samples were taken.

The results are shown in table 14. It is apparent from the data that while the larger applications of gypsum gave the greatest increases of straw they produced practically no increases in grain. The smaller applications, on the other hand, gave not only appreciable increases in straw but also decided increases in grain. From the standpoint of total crop, or straw plus grain, each of the various treatments gave an increase over the check of approximately 25 per cent. In regard to nitrogen utilization, however, the crops

from the plots receiving the heavier treatments contained little more than one-half of their total nitrogen in grain, while those from the other plots contained nearly three-fourths of their total nitrogen in grain.

The percentage of nitrogen in the oats straw plus grain was not perceptibly altered by any of the treatments.

Discussion of results

The ability of gypsum to increase yields of alfalfa under conditions of drouth has been indicated by some of the results presented. The action of gypsum in these cases may have been due to the promotion of root development of the the plants or otherwise increasing their drouth-resisting power, or it may have been the result of soil moisture conservation effected through decreased capillarity or increased water-holding capacity.

That gypsum does increase root development of alfalfa has been shown by Reimer and Tartar (16). Similar results have been obtained under greenhouse conditions: Hart and Tottingham (9) found that gypsum doubled the size of the root system of red clover, while results obtained by the writer (presented in Part I) show that gypsum increased root development of alfalfa as well as of red clover.

Moisture relationships of the soil may be markedly affected by gypsum. King (10) states that a saturated solution of gypsum (1:400) reduced the capillarity of a sandy soil over 20 per cent. An indication of a similar effect is given by the yields in table 12 for the second cutting of the 3-year-old stand of alfalfa. Since the stand was well established it seems that the effect may have been on the moisture-holding capacity of the soil rather than on root development. According to Garver (7) the root system of alfalfa is most susceptible to influence when the plants are two to three months of age.

Results obtained with alfalfa on Ames field no. 2 show an unmistakable benefit from applications of gypsum. At no time in this experiment was moisture a limiting factor. The gypsum therefore acted either as a direct fertilizer, or indirectly by liberating other plant-food or enhancing beneficial microbiological activity. In view of the fact that sulfur produced about the same results as the larger applications of gypsum it is not unlikely that gypsum acted directly as a sulfur fertilizer.

The decrease in effect of the 50- and 150-pound applications after the second cutting is readily explained by assuming that the sulfate applied had been completely removed by the first two crops and by leaching before the third crop began to develop. A similar decrease in effect of small applications of gypsum on alfalfa in eastern Oregon has been noted by Powers (15).

The data showing results obtained with oats suggest that the effects observed may have been due to the influence of gypsum on nitrification. Inasmuch as the smallest treatments gave less straw and more grain than the larger applications, it may readily be assumed that the former increased nitrification sufficiently to favor early growth of the crop, but the larger amounts of gyp-

sum gave a longer continued effect resulting in more vegetative growth at the expense of grain. The decrease in percentage of nitrogen in grain from the plot receiving the largest application of gypsum may be accounted for on the same basis.

Perceptible differences in total nitrogen content of alfalfa hay from the various plots were found. In a few cases the increases noted were probably the result of stunted growth, but in other cases gypsum has increased both the crop yield and the percentage of nitrogen at the same time.

The most important point revealed by analyses of the soil samples is the constancy of lime requirement and reaction of the soil in all plots. While the tests were made on air-dry samples, it is believed that the results are practically the same as would have been obtained in the field. Recent investigations at this station indicate that air-drying does not materially alter either the lime requirement or hydrogen-ion concentration of field soils. Moreover, many of the soils were nearly air-dry when sampled. The obvious conclusion from this work, therefore, is that gypsum in the quantities employed had no effect on the lime requirement or reaction of the various soil types.

The data for soluble nitrates and sulfates cannot be given much significance because of the small number of samples taken and because these came from under growing crops. It is of interest to note, however, that in all cases sulfates were present in considerable excess over nitrates.

Conclusions

While definite conclusions cannot be drawn from one season's results, indications which may serve as a basis for further investigation have been obtained. These are as follows:

1. Gypsum materially increased the growth of alfalfa on various soil types under different conditions.
2. Old, well-established stands of alfalfa as well as new seedings were benefited by treatment with gypsum.
3. Gypsum apparently imparted an appreciable drouth-resisting capacity to alfalfa or to the soil on which it was growing.
4. Gypsum in 300- and 500-pound applications per acre gave longer continued effects than 50- and 150-pound treatments.
5. Gypsum increased the percentage of nitrogen in alfalfa hay in some instances.
6. The smaller applications of gypsum increased the yield of oats grain while the larger applications increased the yield of straw rather than grain.

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EASILY SOLUBLE CALCIUM OF SOILS AS AN INDICATOR OF THEIR RESPONSE TO LIMING[1]

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Many attempts have been made in the past to determine by a simple laboratory test whether or not a soil will respond profitably to the use of lime but the results obtained have not checked well with field results in all cases. It is a common observation, that some soils, which to all tests are strongly acid, will nevertheless grow excellent red clover or alfalfa without the application of lime. The degree of acidity as indicated by the common tests does not give us a true index as to the return to be expected from the application of lime.

It seems that there must be other factors involved that may be as important as the degree of acidity in the determination of the need of a soil for lime. Why some soils give good returns for liming while others showing the same degree of acidity do not, is a question that has not been satisfactorily answered. It was for the purpose of further investigating this phase of the problem and correlating the soluble calcium with actual field results from the use of lime that the present study was undertaken.[3]

HISTORICAL

Rost and Rieger (22) found the response to liming obtained by field tests on four Minnesota soils did not correspond to the acidity as determined by several different methods. Conner (5), Hartwell and Pember (9), Mirasol (19) and others have shown that certain aluminum salts rendered soluble in acid soils, are toxic to plants. Parker and Truog (27) have shown that different plants contain such varying amounts of calcium that it seems probable the actual lack of calcium is a limiting factor to crop production. Truog (31) has shown that plants vary in their feeding power for calcium. Maschhaupt and Sinnige (18), Shedd (25), and others have done considerable work upon the total calcium, and calcium soluble in various solvents in the soil.

Johnson (15), working with samples of widely different soils, found no relation between the hydrogen-ion concentration and the lime requirement by the Veitch and Truog methods. Blair and Prince (2) found that lime reduced the lime requirement and raised the pH value.

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Joffe (14) found that the germination of alfalfa was very poor in a soil with a pH value below 4.5. However, when once established, excellent growth was made in soils having a pH as low as 3.8. Bryan (4) found that the most favorable reaction for soybeans was 6.5.

Swanson, Latshaw and Tague (26) found that soils which were high in calcium soluble in normal and fifth normal HCl, were usually the most alkaline. Also, the soils high in calcium had a higher percentage of the total calcium in forms soluble in dilute HCl than soils low in calcium. Swanson, Gainey, and Latshaw (27) conclude that there is a correlation between the pH value and the calcium content in soils of similar physical texture. Duley (6) found that in all cases tested where the amount of calcium in the soil solution was low the acidity was also low.

Ames (1) has shown that the nitrification of dried blood in a silt loam soil which was low in basic calcium, increased the calcium in solution from 111 p.p.m. in untreated to 225 p.p.m. in treated soils. This is due, he thinks, to the solvent action of HNO_3 liberated in the process of nitrification.

Turpin (33) concludes that crops increase the CO_2 content of the soil air, but different crops affect it differently.

Russell and Appleyard (23) found that the CO_2 of the soil air in a manured soil was decidedly higher than in an untreated soil.

Hoagland (11) found that the concentration of the soil solution was decidedly increased by the presence CO_2 in the soil air. Hoagland and Sharp (10) found that the hydrogen-ion concentration of a soil suspension was not markedly increased by the addition of CO_2 up to 10 per cent. Hoagland (11) concludes that CO_2 may be the most important factor in determining the concentration of the soil solution, especially as regards calcium.

Maschhaupt and Sinnige (18) state that they prefer carbonated water to citric acid as a solvent for solubility determinations, because it is the most important solvent at the disposal of the plant. Duley (6) found that in general, soils having less than 700 pounds calcium per acre soluble in 0.04 *N* carbonated water gave good returns from liming; those soils having more than 700 pounds per acre usually did not give good returns from liming.

PLAN OF INVESTIGATION

In the present investigation samples were collected from experiment fields known to respond differently to applications of lime, and attempts were made to find out the reason for these differences in returns. The calcium soluble in 0.04 *N* carbonated water was determined in all the samples collected, also the "Truog" acidity and hydrogen-ion concentration. The returns from lime, as shown by actual field results, were secured and correlated whenever possible with the calcium soluble in 0.04 *N* carbonated water, "Truog" acidity, pH and fertility.

This investigation is a continuation of work reported by Duley (6). However, it covers a larger number of soils together with a study of the subsurface and subsoil layers.

METHOD OF PROCEDURE

In the fall of 1923, samples were collected from all the Missouri experiment fields. These samples were taken on the check or untreated plots, from three layers; 0 to 7 inches, 7 to 12 inches and 12 to 36 inches. Three borings were made for the 12 to 36-inch sample and six borings for each of the other two samples. At the same time, samples were secured from some of the soil

experiment fields in Kentucky, Iowa, Illinois and Ohio. As soon as the samples arrived, they were taken to the greenhouse and dried in diffused light at moderate temperature. When they became air-dry, they were pulverized in a ball mill pulverizer. Care was taken to prevent, as far as possible, the breaking up of the individual particles. When ground they were passed through a 20-mesh sieve and stored in quart Mason fruit jars fitted with rubber rings.

LABORATORY METHODS

The method followed in this work was an empirical one. The carbonated water was made up to 0.04 *N* because that normality approaches saturation but can always be reached under ordinary laboratory conditions. By making up to a standard normality the effects of temperature and barometric pressure are practically eliminated.

This method is essentially the same as that used by Duley (7) and was first used by Professor E. Truog of the University of Wisconsin.

The equivalent of 12 gm. of oven-dry soil was weighed out of the air-dry samples. This was then extracted with 600 cc. 0.04 *N* carbonated water by shaking for two hours in a horizontal shaking machine.

After filtering through a Büchner funnel a calcium determination was made upon a 500-cc. aliquot.

METHOD OF COMPUTING RETURNS FROM LIME

In order to figure the returns from lime on as nearly an equivalent basis as possible, a money value was set for each crop; wheat $1.00 a bushel, oats $.40 a bushel, corn $.50 a bushel, soybean seed $2.00 a bushel, clover seed $10.00 a bushel, soybean and clover hay $10.00 a ton. The increases for all crops in the rotation were added together and the cost of liming, assumed to be $3.50 a ton, was deducted.

For the purpose of plotting curves, the money values of returns were divided into: good returns, above $3.00 an acre per rotation; fair returns, $1.50 to $3.00 an acre per rotation; and poor returns, less than $1.50 an acre per rotation.

It was impossible to get actual returns from Iowa soils but the returns were listed by J. L. Boatman of the Iowa Experiment Station as fair or good.

SOILS SHOWING STRONG ACIDITY

In table 1 soils having strong to very strong acidity as determined by the Truog (27) method, are listed. The amounts of calcium soluble in 0.04 *N* carbonated water are also given for both the 0 to 7-inch layer and the 7 to 12-inch layer. The returns from liming, on these soils, are given in the last column. These soils all show practically the same acidity by the Truog method, and ordinarily would be expected to give good returns from liming. An examination of the table will show that this is not always the case. The soil from Aledo, Illinois, showing the same acidity as the soil from Wooster, Ohio,

gives a much lower return from the application of lime. However, the amount of soluble calcium is practically twice as great at Aledo as at Wooster. The great difference between the soluble calcium in the 0 to 7-inch layer and the 7 to 12-inch layer at Aledo, Illinois, seems to be characteristic of some of the Brown silt loam soils of Illinois. The pH values of the soils in this table do not seem to be very closely related to either Truog acidity, soluble calcium or returns from lime. The amount of soluble calcium in the 0 to 7-inch layer varies from 423 pounds at Cuba, Missouri, to 945 pounds at Aledo, Illinois. The relation of acidity, soluble calcium and returns from lime are shown graphically in figure 1. The curve showing the returns from lime follows the curve showing the soluble calcium much more closely than it does the acidity curve.

TABLE 1

Soils having strong acidity

LABORATORY NUMBER	SOIL	TRUOG ACIDITY	pH VALUES	Ca PER ACRE SOLUBLE IN 0.04N H_2CO_3			RETURNS FOR LIME
				0 to 7 inches	7 to 12 inches	Total 0 to 12 inches	
				pounds	*pounds*	*pounds*	
7	Cuba, Mo.	4	5.60	423	395	818	$10.73
15	St. James, Mo.	4	5.50	521	510	1,031	6.68
32	Vandalia, Mo.	4	5.50	630	515	1,145	4.53
45	Union, Mo.	4	5.70	510	525	1,035	11.12
47	Wooster, Ohio	4–	5.75	490	531	1,021	9.18
70	Calamus Field, Iowa	4–	6.15	910	*	.....	Fair response
55	Aledo, Ill.	4–	5.30	945	1,665	2,610	–1.05
29	Davenport, Ill.	4–	5.60	520	792	1,312	5.28
66	Scott Co., Iowa	3+	6.40	855	710	1,565	Fair response

* No sample.

SOILS SHOWING MEDIUM ACIDITY

Table 2 in which soils showing medium acidity are listed, shows an even greater variation between Truog acidity, pH value and returns from lime, than table 1. The Windsor, Missouri, soil shows a good return from lime, while the soil from Belmont County, Ohio, having the same degree of acidity and practically the same pH value, shows only a fair return. The soil from Union Grove, Illinois, shows a greater Truog acidity than that from Eldorado Springs, Missouri, but the latter gives a good return for lime, while the former does not. An examination of the amounts of soluble calcium shows that the soil at Windsor, Missouri, giving good returns, has only 570 pounds in the 0 to 7-inch layer as compared with 705 pounds in the 0 to 7-inch layer at Belmont County, Ohio, where fair returns are secured. The Eldorado Springs soil has only 480 pounds of soluble calcium and the Union Grove, Illinois, 880 pounds. Here again the soluble calcium is more closely correlated with the returns from

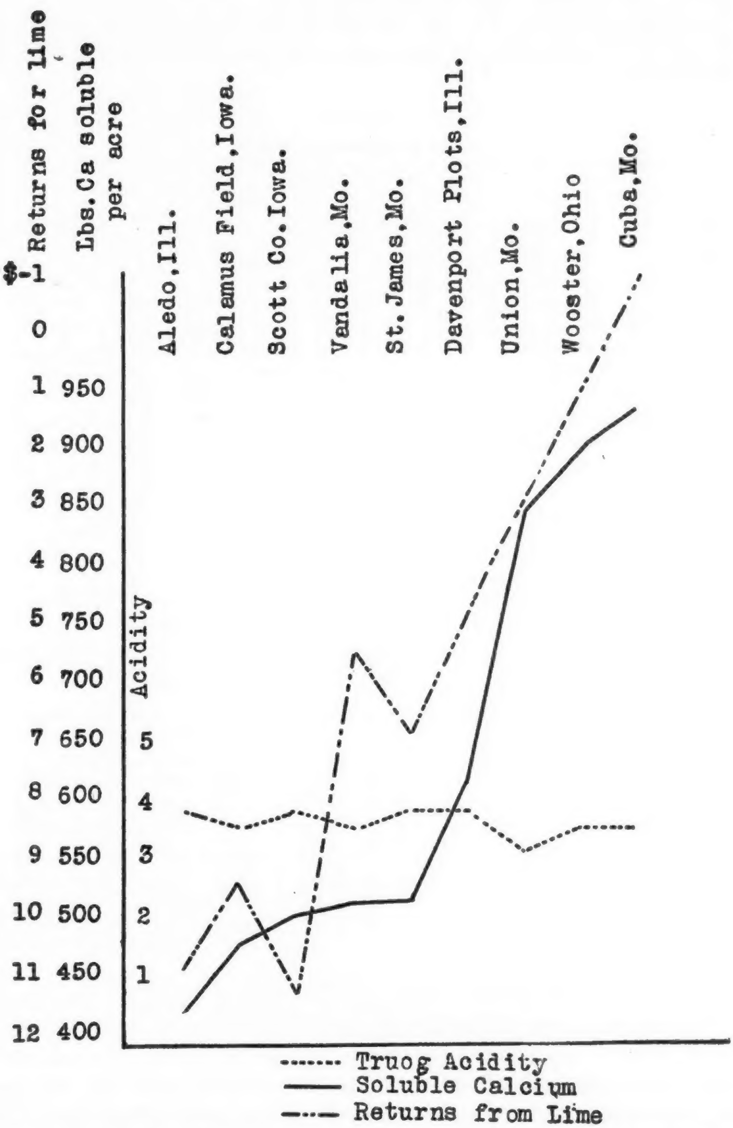

FIG. 1. RELATION OF TRUOG ACIDITY, SOLUBLE CALCIUM AND RETURNS FOR LIME, IN SOILS OF STRONG ACIDITY

liming than is either Truog acidity or pH value. Figure 2 shows graphically the results in table 6. The relation between the soluble calcium and returns from lime is readily seen, but there is no relation between acidity and returns from liming.

TABLE 2

Soils having medium acidity

LABORATORY NUMBER	SOIL	TRUOG ACIDITY	pH VALUES	Ca PER ACRE SOLUBLE IN 0.04*N* H_2CO_3			RETURNS FOR LIME
				0 to 7 inches	7 to 12 inches	Total 0 to 12 inches	
				pounds	*pounds*	*pounds*	
59	Aledo, Ill.	3+	6.35	840	1,045	1,885	−$1.05
64	Clinton Co., Iowa	3+	5.40	600	620	1,220	Fair response
27	Union Grove, Ill.	3+	5.70	880	615	1,495	−0.16
11	Strafford, Mo.	3	5.95	511	425	936	7.25
68	Agronomy Farm, Iowa	3	6.40	533	575	1,108	Good response
9	Eldorado Springs, Mo.	3	5.30	490	428	918	6.28
26	Belmont Co., Ohio	3−	5.50	705	680	1,385	1.58
5	Windsor, Mo.	3−	5.60	570	635	1,205	8.66

TABLE 3

Soils having slight to very slight acidity

LABORATORY NUMBER	SOIL	TRUOG ACIDITY	pH VALUES	Ca PER ACRE SOLUBLE IN 0.04*N* H_2CO_3			RETURNS FOR LIME
				0 to 7 inches	7 to 12 inches	Total 0 to 12 inches	
				pounds	*pounds*	*pounds*	
35	Urbana, Ill.	1+	5.9	1,100	995	2,095	Loss
1	Chillicothe, Mo.	2+	5.6	840	1,010	1,850	No return
3	Maryville, Mo.	3−	5.9	711	855	1,566	−$0.37
17	Russellville, Ky.	2+	6.3	731	773	1,504	1.87
37	Paulding Co., Ohio	1+	6.5	1,370	1,480	2,850	−10.66
13	Willow Springs, Mo.	1	6.7	716	615	1,321	1.37
42	Stark City, Mo.	2	6.7	530	630	1,160	4.04
53	Greenville, Ky.	2	5.7	436	395	831	3.31

SOILS HAVING SLIGHT TO VERY SLIGHT ACIDITY

The results in table 3 in which soils having slight to very slight acidity are listed, show a much better correlation between acidity and returns from liming than soils having medium acidity. However, the Stark City soil does not respond to liming as would be expected from the Truog acidity or pH value. The soluble calcium in this soil being very low the good returns obtained from lime may be explained on this basis, while they could not on the basis of acidity.

Soils having strong or very slight acidity by the Truog method seem to show some general correlation between acidity and returns from liming. This relation does not hold for soils of medium acidity. Here the amount of

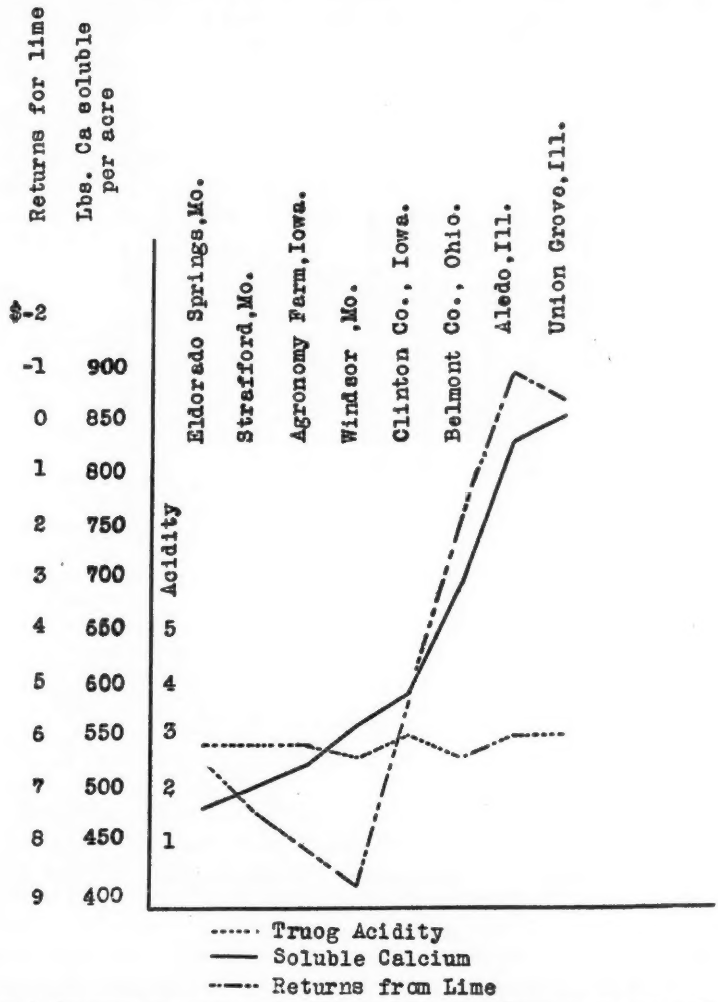

FIG. 2. RELATIONS OF TRUOG ACIDITY, SOLUBLE CALCIUM AND RETURNS FOR LIME, IN SOILS OF MEDIUM ACIDITY

calcium soluble in 0.04 N carbonated water seems to be a much more accurate method of estimating the return to be expected from liming in the case of the soils studied.

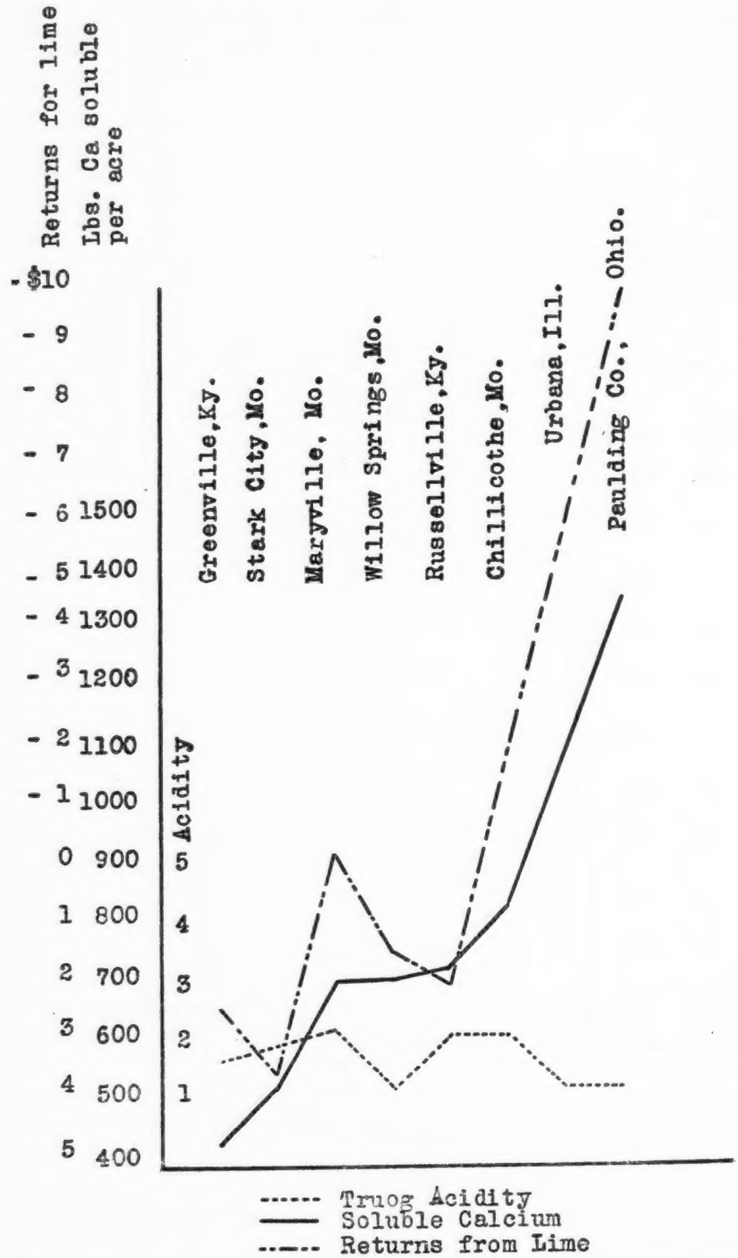

FIG. 3. RELATION OF TRUOG ACIDITY, SOLUBLE CALCIUM AND RETURNS FOR LIME, IN SOILS OF SLIGHT ACIDITY

SOLUBLE CALCIUM CONTENT OF SOILS GIVING GOOD RETURNS FROM LIMING AS COMPARED TO THOSE GIVING POOR RETURNS

Table 4 in which the soils giving good returns from lime are grouped together, gives the Truog acidity, soluble calcium in the surface and subsurface layers, and the returns obtained from applications of lime. There is a variation from slight acidity in the Greenville, Kentucky, sample, to strong acidity in the Vandalia, Missouri, sample. However, these two soils give approximately the same return for liming. No soil in this table contains more than 630 pounds soluble calcium in the surface 7 inches. The average soluble calcium content is 512 pounds for the surface 7 inches and 525 pounds for the subsurface 7 to 12 inches. The average total in the 0 to 12-inch layer is 1038 pounds.

TABLE 4

Soils giving good returns for liming

LABORATORY NUMBER	SOIL	TRUOG ACIDITY	Ca PER ACRE SOLUBLE IN 0.04*N* H_2CO_3			RETURNS FOR LIME
			0 to 7 inches	7 to 12 inches	Total 0 to 12 inches	
			pounds	*pounds*	*pounds*	
45	Union, Mo.	4	510	525	1,035	$11.12
7	Cuba, Mo.	4−	423	395	818	10.73
49	Wooster, Ohio	4−	490	531	1,021	9.18
15	St. James, Mo.	4−	521	510	1,031	6.68
29	Davenport Plots, Ill.	4−	520	792	1,312	5.28
32	Vandalia, Mo.	4	630	515	1,145	4.53
11	Strafford, Mo.	3	511	425	936	7.25
5	Windsor, Mo.	3−	570	635	1,205	8.66
53	Greenville, Ky.	2−	436	395	831	3.31
43	Stark City, Mo.	2	536	630	1,166	4.04
9	Eldorado Springs, Mo.	3	490	428	918	6.28
Average			512.5	525.5	1,038	

Table 5 lists those soils giving a poor return from the application of lime. The Truog acidity in these soils varies from almost strong acidity at Aledo, Illinois, to very slight at Willow Springs, Missouri. However, in spite of the greater Truog acidity at Aledo, Willow Springs seems to give more return for liming. This can be explained upon the basis of the soluble calcium content of the 0 to 7-inch layer. No soil in this table contains less than 705 pounds of soluble calcium in the 0 to 7-inch layer. The average soluble calcium content is 877 pounds in the 0 to 7-inch layer, 896 pounds in the 7 to 12-inch layer and 1773 pounds in the 0 to 12 inches.

Table 6 shows that the soils listed as giving good returns average a much lower content of soluble calcium than those soils giving poor returns. All the soils in table 4 are of average, or lower than average fertility. All of the soils

in table 5 are above the average in fertility, except those at Russellville, Kentucky; Belmont County, Ohio; and Willow Springs, Missouri. It seems that in these exceptions soluble calcium is a more accurate indication of the need for lime than either the acidity or fertility. These are a few cases where general fertility is not a true indication of lime needs. These soils all respond better to the application of nitrogen and phosphorus than to lime.

TABLE 5

Soils giving poor returns for liming

LABORATORY NUMBER	SOIL	TRUOG ACIDITY	Ca PER ACRE SOLUBLE IN 0.04N H_2CO_3			RETURNS FOR LIME
			0 to 7 inches	7 to 12 inches	Total 0 to 12 inches	
			pounds	*pounds*	*pounds*	
59	Aldedo, Ill.	3+	840	1,045	1,885	−$1.05
27	Union Grove, Ill.	3+	880	615	1,495	−0.16
35	Urbana, Ill.	1+	1,100	995	2,095	Loss
1	Chillicothe, Mo.	2+	840	1,010	1,850	Loss
3	Maryville, Mo.	3−	711	855	1,566	−0.37
17	Russellville, Ky.	2+	731	773	1,504	1.87
37	Paulding Co., Ohio	1+	1,370	1,480	2,850	−10.66
13	Willow Springs, Mo.	1	716	615	1,321	1.37
26	Belmont Co., Ohio	3−	705	680	1,385	1.58
Average			877	896	1,773	

TABLE 6

Average calcium soluble in soils giving good returns as compared to average of soils giving poor returns

RETURNS FOR LIME	Ca PER ACRE SOLUBLE IN 0.04N H_2CO_3 (2,000,000 POUNDS)		
	0 to 7 inches	7 to 12 inches	Total 0 to 12 inches
Good returns	512	525	1038
Poor returns	877	896	1773

RELATION OF AMOUNT OF SOLUBLE CALCIUM IN THE 0 TO 7-INCH LAYER AND 0 TO 12-INCH LAYER AND RETURNS FROM LIME

Figure 4 shows graphically the relation of soluble calcium in the 0 to 7-inch layer, to returns from lime. The fields were arranged in the order of their soluble calcium content in the 0 to 7-inch layer. The amount of soluble calcium in each field was then plotted and the points connected with a curve. The returns from lime on the various fields were designated as good (G), fair (F), and poor (P). These values were obtained as previously described. It may be seen from this curve that soils having less than 600 pounds of soluble calcium per acre 7 inches show good returns from lime. Soils having approxi-

mately 600 to 700 pounds have given a fair return, while soils having more than about 700 pounds have not given much return. With the soils in the present investigation, there was not a single exception to this.

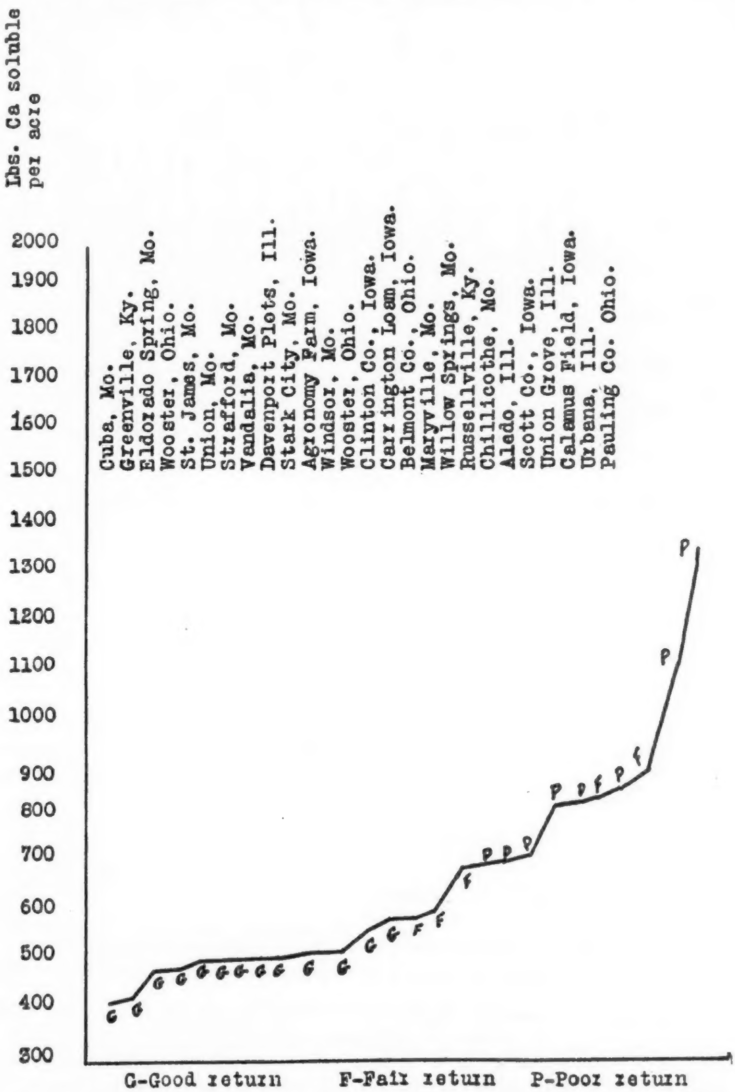

FIG. 4. AMOUNT OF SOLUBLE CALCIUM IN 0 to 7-INCH LAYER AND RETURNS FOR LIME

Figure 5 shows a curve similar to figure 4 except that the amount of calcium soluble in the 0 to 12-inch layer instead of that in the 0 to 7-inch layer is used. This curve shows that those soils which contained less than approximately 1250

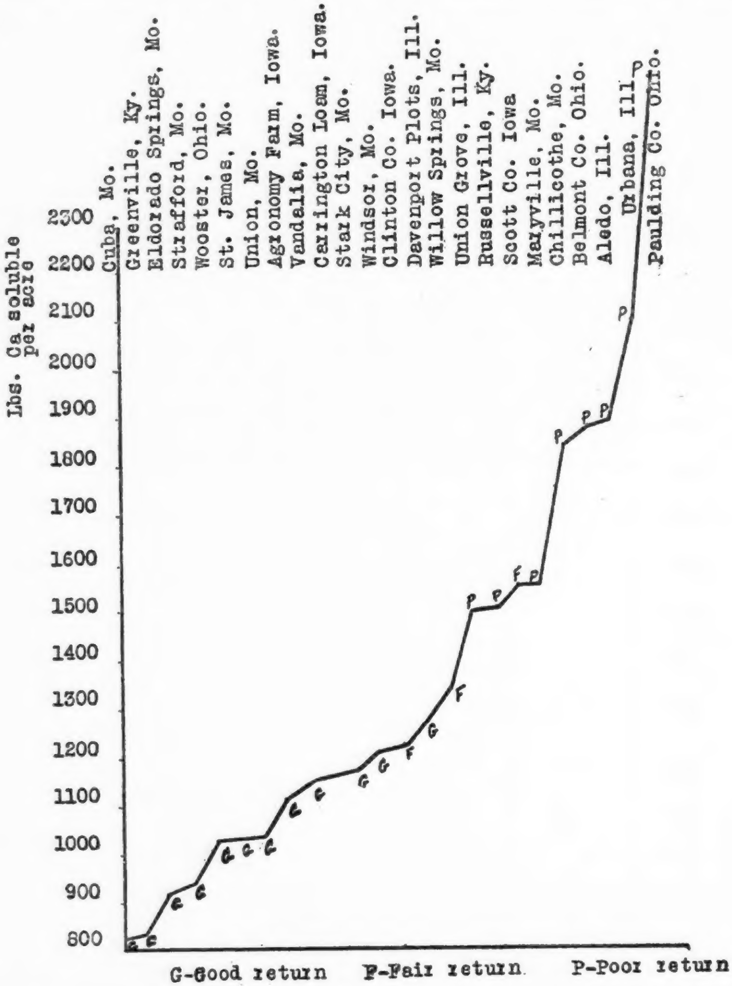

FIG. 5. AMOUNT OF SOLUBLE CALCIUM IN 0 TO 12-INCH LAYER AND RETURNS FOR LIME

pounds of soluble calcium in the 0 to 12-inch layer, have given good returns for liming. Those having between 1250 and 1400 pounds give fair returns and those having more than 1400 pounds give poor returns.

It would seem from the above data unnecessary to determine the soluble

calcium in the 0 to 12-inch layer. In the soils used in the present investigation there is not a case which cannot be explained on the basis of the amount of soluble calcium in the 0 to 7-inch layer as well as if the 0 to 12-inch layer were used.

TABLE 7

Acidity of the different layers of some Missouri soils

LABORATORY NUMBER	SOIL	0 to 7 inches	7 to 12 inches	12 to 36 inches	RETURNS FOR LIME
1	Chillicothe, Mo.	2+	3−	2+	No return
3	Maryville	3−	2+	3	−$0.37
5	Windsor	3−	3	3	8.66
42	Stark City	2	1	2	4.04
13	Willow Springs	1	1+	4−	1.37
45	Union	4	4−	4+	11.12
32	Vandalia	4	4	5	4.53
15	St. James	4−	5−	5−	6.68
9	Eldorado Springs	3	4−	4−	6.28
11	Strafford	3	4−	5−	7.25
7	Cuba	4	5	5	10.73

TABLE 8

Calcium soluble in 0.04 N carbonated water in different layers of some Missouri soils

MISSOURI FIELDS	TRUOG ACIDITY 0 TO 7 INCHES	Ca PER ACRE SOLUBLE IN 0.04N H_2CO_3				RETURNS FOR LIME
		0 to 7 inches	7 to 12 inches	12 to 36 inches	Total 0 to 36 inches	
		pounds	*pounds*	*pounds*	*pounds*	
Chillicothe	2+	840	1,010	3,480	5,330	No return
Maryville	3−	711	855	2,460	4,026	$0.37
Windsor	3−	570	635	1,548	2,753	8.66
Stark City	2	530	630	1,536	2,696	4.04
Willow Springs	1	716	615	1,260	2,591	1.37
Union	4	510	525	1,080	2,115	11.12
Vandalia	4	630	515	800	1,945	4.53
St. James	4	521	510	780	1,811	6.68
Eldorado Springs	3	490	428	880	1,798	6.28
Strafford	3	511	425	688	1,624	7.25
Cuba	5	423	395	600	1,418	10.73

THE ACIDITY AND SOLUBLE CALCIUM IN DIFFERENT LAYERS OF SOME MISSOURI SOILS

Truog acidity tests were made on the samples of the three layers, that is, the 0 to 7-inch layer, the 7 to 12-inch layer, and the 12 to 36-inch layer. The results are listed in table 7. Willow Springs shows only slight acidity in the surface layer and strong acidity in the 7 to 12-inch layer. Stark City shows less acidity in the 7 to 12-inch layer than in either the 0 to 7- or 12 to

36-inch layers. The point most clearly shown in the table is that the acidity varies considerably in the different layers.

Because the acidity was found to vary, an attempt was made to determine the soluble calcium in the various layers and to see if there was any correlation between the soluble calcium and the returns from lime. The results are shown in table 8. The same variations found in table 7 are apparent here. Nothing is explained by including the 12 to 36-inch layer that cannot be explained as easily by using the surface 7 inches. It would seem that Willow Springs should give good returns from lime, on the basis of total soluble calcium in 0 to 36 inches. However, the amount of soluble calcium in the surface 7 inches would lead us to think otherwise. The actual return proves that the latter is true. It seems, therefore, that for practical purposes it is not necessary to determine the soluble calcium in the subsoil.

TABLE 9

Relation of nitrogen content and soluble calcium content to returns from lime

SOIL	TRUOG ACIDITY	Ca SOLUBLE 0 TO 7 INCHES	Ca SOLUBLE 7 TO 12 INCHES	NITROGEN 0 TO 7 INCHES	RETURNS FOR LIME
		per cent	*per cent*	*per cent*	
Chillicothe, Mo.	2+	0.042	0.050	0.287	No return
Paulding Co., Ohio	1+	0.068	0.074	0.256	−$10.66
Urbana, Ill.	1	0.049	0.055	0.215	Loss
Davenport Plots, Ill.	4−	0.026	0.032	0.204	5.28
Maryville, Mo.	3−	0.035	0.042	0.199	−0.37
Union Grove, Ill.	3+	0.044	0.030	0.174	−0.16
Carrington Loam, Iowa	3	0.031	0.042	0.152	Good
Vandalia, Mo.	4	0.031	0.025	0.147	4.53
St. James, Mo.	4	0.026	0.025	0.143	6.68
Union, Mo.	4	0.025	0.026	0.143	11.12
Scott County, Iowa	3+	0.042	0.035	0.132	Fair
Windsor, Mo.	3−	0.028	0.036	0.127	8.66
Agronomy Farm, Iowa	3−	0.026	0.028	0.124	Good
Belmont County, Ohio	3−	0.035	0.034	0.121	1.58
Russellville, Ky.	2+	0.036	0.038	0.102	1.87
Stark City, Mo.	2	0.026	0.031	0.102	4.04
Eldorado Springs, Mo.	3	0.024	0.021	0.097	6.28
Strafford, Mo.	3	0.025	0.021	0.077	7.25
Cuba, Mo.	4	0.021	0.019	0.073	10.73
Greenville, Ky.	2−	0.021	0.019	0.073	3.31
Wooster, Ohio	4−	0.024	0.026	0.072	9.18
Willow Springs, Mo.	1	0.035	0.030	0.056	1.32

RELATION OF FERTILITY TO RETURNS FROM LIMING

In table 9 the soils used in this investigation are listed in the order of their nitrogen content. The Truog acidity and calcium soluble in the 0 to 7-inch and 7 to 12-inch layer are also given. An examination of the table shows that

in general the fertile soils do not give good returns for liming, while those of low fertility do. Although this statement seems to be generally true, it does not hold in all cases. The Davenport plots from Illinois are fertile, as judged by the nitrogen content and field results, still they give a good return for lime. On the other extreme, the soil from Willow Springs, Missouri, is the lowest in nitrogen content, yet it does not give good returns for lime. Since the Davenport plots show only 0.026 per cent and the Willow Springs field 0.035 per cent soluble calcium, the amount of soluble calcium in the 0 to 7-inch layer would explain much better than fertility, the results obtained from liming these fields.

In table 10 are listed some Missouri soils showing total calcium, soluble calcium in different layers, nitrogen, phosphorus, Truog acidity and returns

TABLE 10

Relation of total calcium, calcium soluble in different layers, fertility and returns from liming on some Missouri soils

LABORATORY NUMBER	SOILS	TRUOG ACIDITY	TOTAL CALCIUM*	Ca SOLUBLE IN 0.04N H_2CO_3			NITROGEN*	PHOSPHORUS*	RETURNS FOR LIME
				0 to 7 inches	7 to 12 inches	12 to 36 inches			
			per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	
1	Chillicothe.............	2+	0.844	0.042	0.050	0.043	0.287	0.102	No return
3	Maryville..................	3−	0.535	0.035	0.042	0.030	0.199	0.062	−$0.37
5	Windsor..................	3−	0.595	0.028	0.031	0.019	0.127	0.034	8.66
42	Stark City................	2	0.645	0.026	0.031	0.019	0.102	0.022	4.04
13	Willow Springs............	1	0.418	0.035	0.030	0.015	0.056	0.028	1.32
45	Union.....................	4	0.814	0.025	0.026	0.013	0.143	0.051	11.12
32	Vandalia..................	4	0.744	0.031	0.025	0.010	0.147	0.052	4.53
15	St. James..................	4	0.305	0.026	0.025	0.009	0.143	0.044	6.68
9	Eldorado Springs..........	3	0.380	0.024	0.021	0.011	0.097	0.023	6.28
11	Strafford..................	3	0.405	0.025	0.021	0.008	0.077	0.032	7.25
7	Cuba......................	4−	0.395	0.021	0.019	0.007	0.073	0.034	10.73

* Analyses secured from departmant of agricultural chemistry.

from lime. Willow Springs shows very slight acidity, 705 pounds of soluble calcium in the 0 to 7-inch layer, a small amount of both phosphorus and nitrogen, and poor returns for lime. The poor return from lime can be explained on the basis of soluble calcium but not on the basis of fertility. This soil responds much better to applications of nitrogen and phosphorus than it does to lime, which goes to show that in this particular soil there is no actual lack of calcium as is the case with nitrogen and phosphorus. It seems from this that the need of a soil for lime cannot always be estimated from the phosphorus and nitrogen content of the soil. The soluble calcium again seems to give a closer correlation with the need of a soil for lime, than does the fertility.

SUMMARY

The calcium soluble in 0.04 *N* carbonated water, pH value, acidity by the Truog method, and fertility were determined in samples of soil collected from experiment fields in Missouri, Iowa, Illinois, Kentucky and Ohio. An attempt was made to find the relation, if any, of these factors to the returns from lime secured on these experiment fields.

1. Those soils showing strong acidity by the Truog method, have usually given good returns for the application of lime, but there was a much closer correlation between the amount of easily soluble calcium and the returns from lime.

2. Soils of medium acidity by the Truog method, show a very definite and close relation between the soluble calcium content and returns from lime. There was no relation between Truog acidity, pH value and returns from lime in the case of these soils.

3. Soils showing slight acidity by the Truog method show a much closer relation between acidity and returns from liming than do soils of medium acidity. However, the amount of soluble calcium shows a much closer relation to returns from lime on these soils than does acidity.

4. Soils giving good returns from lime applications show an average soluble calcium content of 512 pounds in the 0 to 7-inch layer and those giving poor returns average 877 pounds in the 0 to 7-inch layer. Many of these soils have the same acidity by the Truog method.

5. The amount of calcium soluble in 0.04 *N* carbonated water in the 0 to 7-inch layer was found to be closely related to the returns for lime. All those soils studied, having less than about 650 pounds of calcium soluble in 0.04 *N* carbonated water have given good returns for lime while none having more than 700 pounds of soluble calcium, has given good returns.

6. The amount of soluble calcium and the acidity vary in the different layers of soil. However, the data presented do not show a necessity for determining the soluble calcium in any except the surface layer.

7. There was a general relation between the fertility of the soils studied and the returns obtained from lime. The Davenport plots are an exception, however, which is best explained on the basis of soluble calcium content. The case at Willow Springs shows that the fertility as judged by nitrogen, phosphorus and total calcium content, is not always an index to the returns to be expected from the use of lime.

8. There seems to be no very close relation between the pH value and the amount of calcium soluble in 0.04 *N* carbonated water.

9. From the results with the soils examined in this study the amount of calcium soluble in 0.04 *N* carbonated water was found to be a much more accurate means of judging the returns to be expected of any of these soils from the use of lime, than was a determination of the soil acidity.

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THE INFLUENCE OF LIMING, TEMPERATURE AND COMPACTION ON THE MOVEMENT OF SOLUBLE SALTS IN SOILS

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Such questions as the effect of liming on the activity of fertilizer salts in soils, the effect of different temperature conditions on such additions, and the effect of compaction on salt distribution, have a great practical interest as well as the scientific one. Seasonal variations in temperature occur in nearly all soils; the reactions of different soils are not the same, nor are the cultural conditions uniform in any way. Consequently, these factors may play an important part in the solution, dissemination and final utilization of fertilizer salts in soils. The following is a continuation of the work previously reported in two publications from this station (2, 3).

METHODS

Glass cylinders 8 inches long by $1\frac{7}{8}$ inches in diameter were set up in the following manner for each salt used:

To 100 gm. of soil carefully mixed with 2 gm. of finely ground salt, water was added until the optimum moisture content was obtained. For the sand, this was about 5 per cent, and for the clay loam about 20 per cent. The 100 gm. of salt-treated soil was then compacted in the bottom of a cylinder, and the height marked on the glass. Soil moistened to the same water-content was then placed in the cylinder and compacted until the tube was filled. Both ends were sealed with paraffin.

In the same manner another set of tubes were prepared, 0.04 N $Ca(OH)_2$ instead of distilled water being used for moistening the soils. Two cylinders of each treatment provided means of obtaining data for two periods of time. The series were kept at a uniform temperature of above 25°C. and sampled after 5- and 15-day periods, respectively. One-inch sections were removed, and the moisture content determined by drying a sample in the oven at 103°C. for 48 hours, and calculating the percentage of moisture on the basis of oven-dry soil. The salt content was measured by means of the freezing point method devised by Bouyoucos (1).

EXPERIMENTAL RESULTS

I. Effect of the use of calcium hydroxide upon the rate and amount of movement of potassium chloride, mono-calcium phosphate and sodium nitrate in soils of different texture

The results of this study, shown in tables 1, 2 and 3, are of interest from several points of view. Potassium chloride is consistently affected by the liming treatment, moving about an inch farther in limed tubes than in watered

TABLE 1

Movement of potassium chloride through limed and water-treated soils

DISTANCE FROM SALT LAYER	WITH 0.04 N $Ca(OH)_2$				WITH DISTILLED WATER			
	5 days		15 days		5 days		15 days	
	Freezing point depression	Moisture content	Freezing point depression	Moisture content	Freezing point depression	Moisture content	Freezing point depression	Moisture content
inches	°*C.*	*per cent*	°*C.*	*per cent*	°*C.*	*per cent*	°*C.*	*per cent*
				Clay loam				
6	0.010	19.82	0.015	19.22	0.008	19.04	0.006	19.00
5	0.010	19.70	0.040	19.12	0.007	19.00	0.008	19.11
4	0.015	19.80	0.060	19.62	0.008	19.10	0.028	19.03
3	0.035	19.00	0.065	19.16	0.007	18.75	0.029	19.06
2	0.040	18.73	0.070	18.64	0.017	19.10	0.054	19.46
1	0.205	19.40	0.120	19.56	0.145	19.00	0.150	19.82
0	0.440	19.23	0.320	19.77	0.460	19.50	0.340	20.21
0	0.520	19.50	0.340	19.57	0.510	19.96	0.345	20.11
				Medium sand				
6	0.005	4.12	0.005	4.00	0.003	4.01	0.003	3.90
5	0.005	4.12	0.006	4.07	0.004	4.04	0.002	3.96
4	0.006	4.14	0.004	4.07	0.002	3.88	0.006	4.01
3	0.005	4.18	0.015	4.10	0.003	4.16	0.004	3.98
2	0.022	4.08	0.102	3.80	0.010	4.10	0.024	4.00
1	0.111	3.78	0.220	3.78	0.113	3.73	0.130	4.00
0	0.370	3.54	0.260	3.67	0.350	3.50	0.290	4.22
0	0.395	3.72	0.272	3.70	0.368	4.06	0.310	4.10

tubes. The influence appears to be more pronounced in the fine-textured soil. It is difficult to explain this action. Previous treatment with a calcium salt charges the soil mass with an easily replaceable base, with which potassium is readily exchanged. This results in the liberation of another highly soluble salt in the soil solution. In the water-moistened soils the amount of readily replaceable and soluble base is less, and there may be produced less soluble compounds than potassium chloride. Physical fixation of the salts in solution in this case may also be less than in limed soils. The freezing point depressions obtained in the salt layers themselves are not indicative of any definitely

higher concentration in the limed soils, however. Possibly the presence of lime insures a more rapid and progressive reaction with the fertilizer salt, which may thus travel along from particle to particle at a higher rate of speed than would be possible under normal soil conditions.

Sodium nitrate is also distributed somewhat more readily in limed soils. The advantage in liming is, however, slight in the clay loam soil. The conditions in this group of data are quite comparable with those for potassium

TABLE 2

Movement of mono-calcium phosphate in limed and water-treated soils

DISTANCE FROM SALT LAYER	WITH 0.04 N $Ca(OH)_2$				WITH DISTILLED WATER			
	5 days		15 days		5 days		15 days	
	Freezing point depression	Moisture content	Freezing point depression	Moisture content	Feezing point depression	Moisture content	Freezing point depression	Moisture content
inches	*°C.*	*per cent*	*°C.*	*per cent*	*°C.*	*per cent*	*°C.*	*per cent*
				Clay loam				
6	0.004	24.30	0.005	24.54	0.004	23.56	0.005	23.60
5	0.004	24.56	0.004	24.32	0.003	23.40	0.005	23.80
4	0.005	24.75	0.004	24.00	0.004	23.25	0.004	24.10
3	0.006	24.20	0.006	24.65	0.004	23.70	0.005	24.18
2	0.005	24.20	0.005	25.00	0.003	23.90	0.004	23.90
1	0.008	24.50	0.009	24.20	0.005	23.56	0.008	23.22
0	0.070	24.55	0.075	25.10	0.055	23.40	0.055	24.14
0	0.075	25.04	0.090	25.02	0.085	23.20	0.075	23.78
				Medium sand				
6	0.004	9.14	0.005	4.12	0.004	9.12	0.003	4.00
5	0.006	8.74	0.004	4.35	0.006	8.60	0.003	4.29
4	0.004	9.04	0.005	4.36	0.003	8.74	0.002	4.26
3	0.003	8.90	0.004	4.51	0.003	8.92	0.004	4.37
2	0.005	8.94	0.002	4.58	0.004	8.80	0.002	4.41
1	0.004	9.30	0.015	4.85	0.100	9.10	0.015	4.56
0	0.360	8.50	0.290	4.78	0.380	8.40	0.340	4.60
0	0.415	8.60	0.330	4.82	0.430	8.25	0.350	4.65

chloride with regard to the replacement, absorption and reactivity of salts in the soil. The most striking results are those obtained with mono-calcium phosphate which was not influenced by any treatment, and was not mobile in any instance. The absorption of this salt must be extremely intense and complete, for no movement is recorded.

The nature of the salt added to a soil is important in determining its distribution. The more soluble and highly ionized salts are most readily dispersed. The movement of salts is also dependent on the reaction of soils and their textural condition, the latter being operative somewhat indirectly, however,

inasmuch as certain soils are influenced more readily by treatment with lime, temperature change, and so on.

The moisture equilibria in these studies were quite uniform and appeared to be unaffected by the conditions of the experiments.

II. Effect of temperature upon the rate of movement of potassium chloride in soils

Several tubes were prepared in exactly the same manner and kept at temperatures of 0°, 15° and 65°C. respectively, for 10 days. The temperature of 0°C. was maintained by packing the tubes in a bath of melting ice. Other

TABLE 3

Movement of sodium nitrate in limed and water-treated soils

DISTANCE FROM SALT LAYER	WITH 0.04 N $Ca(OH)_2$				WITH DISTILLED WATER			
	5 days		15 days		5 days		15 days	
	Freezing point depression	Moisture content	Freezing point depression	Moisture content	Freezing point depression	Moisture content	Freezing point depression	Moisture content
inches	°C.	*per cent*	°C.	*per cent*	°C.	*per cent*	°C.	*per cent*
				Clay loam				
6	0.005	24.48	0.006	25.00	0.005	22.90	0.005	23.10
5	0.006	24.82	0.006	24.84	0.003	23.58	0.004	23.12
4	0.005	23.90	0.004	24.84	0.003	23.10	0.004	23.75
3	0.005	24.43	0.010	24.75	0.004	23.18	0.010	23.01
2	0.010	25.18	0.120	25.10	0.010	23.45	0.080	23.20
1	0.310	24.84	0.495	24.80	0.430	23.10	0.520	23.28
0	1.240	23.95	1.030	24.40	1.420	22.68	1.025	23.75
0	1.400	23.96	1.255	24.01	1.430	22.08	1.185	23.22
				Medium sand				
6	0.006	4.50	0.003	4.05	0.004	4.28	0.004	4.09
5	0.004	4.59	0.004	4.28	0.006	4.97	0.004	4.27
4	0.006	4.50	0.002	4.50	0.008	4.50	0.005	4.58
3	0.010	4.02	0.040	4.52	0.008	5.52	0.030	4.49
2	0.215	4.79	0.205	4.74	0.010	4.79	0.145	4.81
1	0.325	4.90	0.570	4.81	0.125	4.01	0.305	4.74
0	0.620	4.65	0.640	4.49	0.535	4.47	0.516	4.55
0	0.624	4.10	0.785	4.40	0.610	4.52	0.665	4.40

tubes were immersed in a water bath, which remained at 15°C. while the high temperature of 65°C. was maintained in an electric drying oven.

The data given in table 4 are regular and establish the fact that higher temperatures increase the activity of salt movement. There were no noteworthy movements of moisture. At the temperature of melting ice the movement of salt was very slight, and in no case could it be detected more than 1 inch from the deposit. In comparison with this the salt moved 2 and often 3 inches

outward at the temperature of 15°C. Moreover, a larger quantity of salt was distributed at this temperature since greater depressions were obtained. At 65°C., a temperature about four times as high as the preceding, a further increase in rate and amount of salt moved, was observed. At this temperature, however, untreated soils are more soluble, consequently higher readings would result. Thus, while the data show concentrations throughout, some of

TABLE 4

Effect of temperature on the movements of salt and moisture induced by the addition of 1 per cent KCl to silt loam and medium sand

DISTANCE FROM SALT LAYER	SILT LOAM				MEDIUM SAND			
	At low moisture		At high moisture		At low moisture		At high moisture	
	Freezing point depression	Moisture content	Freezing point depression	Moisture content	Freezing point depression	Moisture content	Freezing point depression	Moisture content
inches	°*C.*	*per cent*	°*C.*	*per cent*	°*C.*	*per cent*	°*C.*	*per cent*
Temperature 0°C.—10 days								
5	0.006	11.38	0.006	18.83	0.002	3.76	0.003	8.24
4	0.005	11.49	0.006	19.01	0.004	3.83	0.003	8.25
3	0.003	11.68	0.007	19.13	0.005	4.00	0.003	8.32
2	0.008	11.65	0.005	18.83	0.004	4.54	0.005	8.40
1	0.115	12.02	0.120	18.84	0.105	5.44	0.085	8.27
0	0.560	11.62	0.530	17.38	0.395	4.12	0.615	8.25
Temperature 15°C.—10 days								
5	0.005	10.30	0.006	17.80	0.005	3.53	0.005	8.42
4	0.005	10.48	0.006	17.69	0.006	3.76	0.004	8.33
3	0.004	10.55	0.040	17.92	0.006	3.48	0.115	8.59
2	0.075	10.93	0.180	17.85	0.055	3.66	0.325	8.39
1	0.350	10.88	0.290	17.95	0.295	3.94	0.410	8.12
0	0.560	11.62	0.530	17.38	0.395	4.12	0.615	8.25
Temperature 65°C.—10 days								
5	0.025	9.52	0.025	17.00	0.025	2.53	0.035	7.99
4	0.035	9.76	0.025	15.95	0.035	1.96	0.035	7.52
3	0.050	9.95	0.040	16.10	0.055	2.01	0.065	7.37
2	0.090	9.49	0.105	16.23	0.195	2.20	0.265	7.19
1	0.280	9.46	0.230	15.95	0.595	2.26	0.445	7.35
0	0.570	9.80	0.490	15.90	0.695	2.47	0.735	6.31

this is due to high temperature alone. There were small differences in concentration of corresponding layers of silt loam and sand. Sand showed a tendency to allow the translocation of a greater amount of soluble material. It is thus believed possible almost to eliminate such factors as texture and moisture content by the use of comparatively high temperatures. Under such conditions a fertilizer salt is distributed in soils at a rapid rate.

A consideration of these facts has led to these hypotheses:

(*a*) Since the speed of most chemical reactions is increased by the application of heat, and since increases in activity have occurred in soils treated with salt solutions when higher temperatures were used, it appears reasonable to believe that the movement of salts through soil may have been due in part to chemical processes. (*b*) Increases in the rate of diffusion are also obtained under increased temperatures, hence, increases in rates of salt translocation may be a direct effect of this process.

TABLE 5

Effect of different degree of compaction on the movement of potassium chloride in silt loam and medium sand in 10 days

DISTANCE FROM SALT LAYER	SILT LOAM				MEDIUM SAND			
	At high moisture		At low moisture		At high moisture		At low moisture	
	Freezing point depression	Moisture content	Freezing point depression	Moisture content	Freezing point depression	Moisture content	Freezing point depression	Moisture content
inches	°C.	*per cent*	°C.	*per cent*	°C.	*per cent*	°C.	*per cent*
				Compact				
3	0.015	17.84	0.005	9.94	0.007	7.19	0.004	2.95
2	0.070	17.10	0.006	9.98	0.020	7.36	0.120	2.98
1	0.180	17.00	0.120	10.00	0.230	7.62	0.190	3.00
0	0.240	17.00	0.420	10.08	0.540	7.79	0.470	3.14
1	0.160	16.96	0.290	10.06	0.310	8.24	0.420	3.15
2	0.110	17.21	0.010	9.96	0.210	8.76	0.070	3.00
3	0.054	17.40	0.006	9.99	0.060	9.06	0.005	3.00
4	0.040	17.50	0.006	10.00	0.004	9.70	0.004	2.96
				Loose				
3	0.040	17.20	0.003	9.85	0.008	7.29	0.005	2.90
2	0.080	17.41	0.010	9.78	0.040	7.41	0.007	2.90
1	0.200	17.30	0.130	9.98	0.240	7.83	0.160	3.00
0	0.290	17.95	0.450	10.15	0.370	7.84	0.340	3.36
1	0.170	17.35	0.180	9.98	0.290	8.22	0.320	3.10
2	0.080	17.50	0.010	10.12	0.220	8.70	0.040	3.10
3	0.020	17.50	0.005	10.05	0.008	9.12	0.004	3.15
4	0.010	17.48	0.004	9.95	0.003	9.74	0.004	3.20

Because there is a lack of available data concerning relative rates of action of the chemical and physical processes in soils, definite ideas cannot be advanced at this time. The difficulty in obtaining these data is made greater by the fact that a large number of reactions may be in progress at one time which produce a resultant of reactions not easily resolved into its components. For instance, while potassium is being replaced in the solution by calcium there is undoubtedly also occurring at the same time a replacement of potassium by magnesium. The rate of reaction between potassium and calcium being different, the velocity of the action between potassium and magnesium

makes impossible the determination of the amount of the original element active in each case. The explanation of the movements therefore, must be left as a general idea of physico-chemical relationships, of which rate of solubility, ionization and mobility of ions undoubtedly play important parts.

III. Effect of different degrees of compaction upon the movement of potassium chloride in soils

The tubes which were compacted held 500 gm. of sand and 450 gm. of silt loam with volume weights of 1.37 and 1.23 respectively, while the tubes which were not compacted held 450 gm. of sand and 400 gm. of silt loam with volume weights of 1.23 and 1.10 in each respective case. The compaction required in the first instance was appreciable, while scarcely more than spreading about was necessary in the loosely filled tubes.

The results are given in table 5.

The comparison of the distance and the amount of salt withdrawn to the outer layers in loose and compact soils show small differences. There were no appreciable advantages shown in any instances by the compact soil. The results were especially uniform when high moisture contents were used, and the trend of the data as a whole would not permit drawing conclusions in favor of compacting the soil to facilitate salt movements.

It is thought probable that under conditions of low moisture the differences in movement might be more clearly seen, since the difficulties for contact in a loose soil would surely be greater than those in a compact one. This lack of contact was probably not a limiting factor at the moisture contents used.

SUMMARY

1. Previous treatment with lime water brought about more rapid distribution of potassium chloride and sodium nitrate in soils of both heavy and light textural characteristics. Mono-calcium phosphate is fixed, and shows no movement whatever.

2. Salts move very slowly in a soil kept at a temperature of melting ice. At 15°C. the movement of salt is increased, while at 65°C. a very rapid translocation occurs.

3. Compaction studies did not show any advantage for either loose or compact soil, as far as salt movement is concerned. At extremely low moisture contents this factor may become important.

4. The intricacy and number of simultaneous reactions between soils and fertilizer salts make it extremely difficult to account for the results obtained, but such things as temperature, reaction of the soil, solubility of the salt, the mobility of its ions, and the ability to bring about replacement reactions appear to be of utmost importance in determining the distribution of fertilizers.

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THE AVAILABILITY OF NITROGEN IN NITRATE OF SODA, AMMONIUM SULFATE, AND DRIED BLOOD WHEN THE AMOUNTS OF PHOSPHORIC ACID AND POTASH ARE VARIED[1]

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In studying the availability of nitrogenous fertilizers in the past, much stress has been laid on results obtained with different nitrogenous materials when the supply of phosphoric acid and potash is kept constant (2, 3, 5). This is as it should be, provided the supply of these minerals is adequate for optimum growth and at the same time not greatly in excess.

There is a possibility, however, that in some of this work, at least, attention may have been too much focused on an excess application of minerals, rather than on the optimum requirements for the conditions as they existed.

In this experiment, which was started in 1922, an attempt has been made to study the availability of three nitrogenous materials separately, and also in a mixture of the three, in the presence of varying amounts of phosphoric acid and potash.

Reports of the work for 1922 and 1923 have already appeared (1, 5).

PLAN OF EXPERIMENT

Sixty soil cylinders, of the type that has been in use at this station for a number of years, arranged in two sets of 30 each, were filled with topsoil to the depth of about 10 inches and treated with nitrogenous fertilizers according to the plan given in table 1.

As will be noted the cylinders are arranged in pairs, there being three pairs for each nitrogen treatment. This arrangement provides for three different amounts of phosphoric acid, in the ratio of 1:2:3, according to the diagram. The potash treatment is uniform for the entire set of 30 cylinders. The second set of 30 cylinders differs from the first in that the amount of potash is double that used in the first set.

The actual amounts of fertilizers used per cylinder were as follows:

Nitrogen—10 gm. of c.p. nitrate of soda and equivalent amounts of the other materials.

Phosphoric acid—10, 20 and 30 gm. of 16 per cent acid phosphate.

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Potash—2.1 and 4.2 gm. of c.p. potassium chloride.

Lime—used in the form of ground limestone to bring the reaction to about pH 6.6 to 7.0.

For the check cylinders, then, the relative amounts of the fertilizing constituents would be as shown in table 2, and for the nitrogen treated cylinders as in table 3.

TABLE 1

Plan of experiment

SOURCE OF NITROGEN	SINGLE PORTION P_2O_5	DOUBLE PORTION P_2O_5	TRIPLE PORTION P_2O_5
No nitrogen (check)	⊗ ⊗	⊗ ⊗	⊗ ⊗
Nitrate of soda	⊗ ⊗	⊗ ⊗	⊗ ⊗
Ammonium sulfate	⊗ ⊗	⊗ ⊗	⊗ ⊗
Dried blood	⊗ ⊗	⊗ ⊗	⊗ ⊗
⅓ nitrogen from each	⊗ ⊗	⊗ ⊗	⊗ ⊗

TABLE 2

Relative amounts of fertilizing constituents for the check cylinders

N	P_2O_5	K_2O
0	5	4 and 8
0	10	4 and 8
0	15	4 and 8

TABLE 3

Relative amounts of fertilizing constituents for the nitrogen-treated cylinders

N	P_2O_5	K_2O
5	5	4 and 8
5	10	4 and 8
5	15	4 and 8

The soil used is a silt loam which was distinctly acid in the beginning but which was corrected by the use of ground limestone as already mentioned. The cylinders have a surface area of about 3 square feet, have natural drainage, and are exposed to natural weather conditions. In 1922 two crops were grown; first, a crop of barley for which the fertilizers were applied; and second, sor-

ghum which was grown as a residual crop without further fertilizer treatment. In 1923 a single crop of corn was grown. This was followed by a crop of oats which was left to die down and form a mulch during the winter.

CROPS OF 1924

Early in the spring of 1924 the soil was prepared and fertilizers were applied in accordance with the plan. Dwarf Essex rape was seeded on May 6. A good uniform stand was secured and the plants on cylinders that received the complete fertilizer made good growth through the season. Those that received no nitrogen made very poor growth. The rape was harvested July 14, dried and prepared for analysis. The soil was then immediately prepared and seeded to Japanese buckwheat without further fertilizer treatment. This crop was seeded to utilize any nitrogen not taken by the first crop.

The results for the rape are shown in table 4. In studying this table, three points should be kept in mind: first, the form of the nitrogenous fertilizer; second, the amount of phosphoric acid used; and third, the amount of potash used.

YIELDS OF DRY MATTER

On an average the yields of dry matter are slightly higher for the section receiving the single portion than for the one receiving the double portion of potash. In both sections there is a remarkably close agreement in the yields for the three different amounts of phosphoric acid, that is, the larger applications gave practically no increase in yields. Likewise there is a close agreement throughout in the yields with nitrate of soda and ammonium sulfate. Notwithstanding this, the total yield of nitrogen is greater in every case with nitrate of soda than with ammonium sulfate. This is due to the fact that without exception, the percentage of nitrogen is higher in the dry matter from the nitrate of soda cylinders than in that from the ammonium sulfate cylinders. Indeed, of all the nitrogenous treatments the ammonium sulfate samples show the lowest percentage of nitrogen in the dry matter. A yield with ammonium sulfate equal to that with nitrate of soda might be construed as meaning that rape utilizes nitrogen in the form of ammonium sulfate more efficiently than in the form of nitrate of soda. Before arriving at such a conclusion, however, further work must be done.

The yields with dried blood alone were approximately 70 to 75 per cent of those with nitrate of soda and ammonium sulfate. When the nitrogen was taken from the three sources the yields were slightly less than the yields with ammonium sulfate alone.

PERCENTAGE OF NITROGEN RECOVERED

In the percentage of nitrogen recovered there is close agreement between the results for the two potash sections. This is emphasized in the statement

TABLE 4

Rape (first crop), 1924

NITROGEN TREATMENT	DRY MATTER	NITROGEN		NITROGEN RECOVERED	DRY MATTER	NITROGEN		NITROGEN RECOVERED	DRY MATTER	NITROGEN		NITROGEN RECOVERED	DRY MATTER	NITROGEN	NITROGEN RECOVERED
	gm.	*per cent*	*gm.*	*per cent*	*gm.*	*per cent*	*gm.*	*per cent*	*gm.*	*per cent*	*gm.*	*per cent*	*gm.*	*gm.*	*per cent*
	Ratio 5-5-4				Ratio 5-10-4				Ratio 5-15-4				Average		
A. Check	25.1	1.550	0.389	.....	28.4	1.628	0.461	.....	33.7	1.369	0.461	.....	29.1	0.437	.....
B. Nitrate of soda	98.8	1.219	1.203	49.42	108.0	1.193	1.289	50.27	106.5	1.196	1.274	49.36	104.4	1.255	49.68
C. Ammonium sulfate	101.9	1.073	1.094	42.81	96.0	1.158	1.109	39.34	108.6	1.082	1.177	43.47	102.2	1.127	41.87
D. Dried blood	74.0	1.246	0.922	32.36	75.7	1.214	0.919	27.81	77.7	1.161	0.902	26.78	75.8	0.914	28.98
E. ⅓ nitrogen from each	95.3	1.175	1.118	44.26	90.1	1.193	1.075	37.28	89.9	1.128	1.014	33.58	91.8	1.069	38.37
Average of 4 treated cylinders	92.5	1.178	1.084	42.21	92.5	1.190	1.098	38.68	95.7	1.142	1.092	38.30	93.6	1.091	39.73
	Ratio 5-5-8				Ratio 5-10-8				Ratio 5-15-8				Average		
F. Check	24.1	1.681	0.403	.....	25.1	1.654	0.410	.....	27.2	1.528	0.415	.....	25.5	0.409	.....
G. Nitrate of soda	100.4	1.281	1.287	53.67	101.6	1.184	1.201	48.03	99.4	1.206	1.198	47.54	100.5	1.229	49.75
H. Ammonium sulfate	99.1	1.105	1.095	42.02	100.6	1.123	1.126	43.47	94.7	1.123	1.061	39.22	98.1	1.094	41.57
I. Dried blood	70.3	1.250	0.878	28.84	63.1	1.337	0.843	26.29	66.6	1.330	0.882	28.35	66.7	0.868	27.83
J. ⅓ nitrogen from each	93.2	1.202	1.120	43.53	82.1	1.249	1.022	37.16	82.0	1.214	0.994	35.15	85.8	1.045	38.61
Average of 4 treated cylinders	90.8	1.210	1.095	42.02	86.9	1.223	1.048	38.74	85.7	1.218	1.034	37.57	87.8	1.059	39.44

of averages in table 5. The results for the two potash treatments are so close as to be easily within the limit of error.

From these figures it would appear that the larger amounts of phosphoric acid cause a slight depression in the percentage of nitrogen returned in the crop. A study of the figures in table 4 showing nitrogen recovery from the different nitrogenous materials, brings out the fact that there is very little difference in any case between the recoveries with the single and the double portions of potash. In most cases the agreement is so close as to be within the limit of error. It is thus clear that increasing the amount of potash had practically no effect on the nitrogen recovery. This relationship is shown in the general averages for the two sections.

The highest average recovery was almost 50 per cent, with nitrate of soda, and the lowest a little under 30, with dried blood. The recovery was slightly higher with ammonium sulfate than with the combination of the three materials. It is significant that in a carefully controlled experiment of this kind, the immediate crop, taking averages, gets scarcely 40 per cent of the applied nitrogen.

TABLE 5

Nitrogen recovered

	SINGLE PORTION P_2O_5	DOUBLE PORTION P_2O_5	TRIPLE PORTION P_2O_5
	per cent	*per cent*	*per cent*
Average for the four nitrogen treatments using single portion of potash	42.21	38.68	38.30
Average for the four nitrogen treatments using double portion of potash	42.02	38.74	37.57

THE RESIDUAL CROP—BUCKWHEAT

Table 6 gives the results obtained with the buckwheat which was grown as a residual or second crop. Attention may be called to the fact that with the exception of the dried blood treatments, the yields from the check cylinders were almost as large as from those that received the nitrogen treatments. This must undoubtedly be atrributed to the fact that the first crop drew much more heavily on the available plant-food and moisture, in the nitrogen treated cylinders, than in the check cylinders. The larger yields with the dried blood compensate to some extent for the smaller yields with this material in the case of the first crop. In this connection it will be remembered that the yields of rape with the dried blood were smaller than with any of the other treatments. This helps to explain why dried blood usually shows a lower availability than nitrate of soda or ammonium sulfate. Apparently it does not decompose rapidly enough for a quick growing crop to utilize as much of it as of the other materials. If a second crop is grown some of this residual dried blood nitrogen is left for that crop, whereas in the case of the nitrate of soda or sulfate of ammonia the first crop utilizes the bulk of the nitrogen that is not otherwise

TABLE 6

Buckwheat (second crop), 1924

NITROGEN TREATMENT	DRY MATTER	NITROGEN		NITROGEN RECOVERED	DRY MATTER	NITROGEN		NITROGEN RECOVERED	DRY MATTER	NITROGEN		NITROGEN RECOVERED	DRY MATTER	NITROGEN	NITROGEN RECOVERED
	gm.	*per cent*	*gm.*	*per cent*	*gm.*	*per cent*	*gm.*	*per cent*	*gm.*	*per cent*	*gm.*	*per cent*	*gm.*	*gm.*	*per cent*
	Ratio 5-5-4				Ratio 5-10-4				Ratio 5-15-4				Average		
A. Check	59.9	1.051	0.629	.....	69.0	1.078	0.744	.....	67.7	1.133	0.766	.....	65.5	0.713	......
B. Nitrate of soda	63.0	1.205	0.750	7.35	73.4	1.173	0.860	7.04	66.2	1.158	0.767	0.06	67.5	0.792	4.82
C. Ammonium sulfate	67.6	1.151	0.778	9.05	63.2	1.209	0.764	1.21	67.4	1.160	0.781	0.91	66.1	0.774	3.72
D. Dried blood	84.6	1.197	1.013	23.32	91.8	1.169	1.073	19.98	88.6	1.182	1.047	17.06	88.3	1.044	20.12
E. ⅓ nitrogen from each	71.4	1.236	0.882	15.36	78.2	1.127	0.887	8.32	77.4	1.115	0.863	5.89	75.7	0.875	9.86
Average of 4 treated cylinders	71.7	1.197	0.856	13.77	76.7	1.170	0.895	9.14	74.9	1.154	0.865	5.98	74.4	0.872	9.63
	Ratio 5-5-8				Ratio 5-10-8				Ratio 5-15-8				Average		
F. Check	69.3	1.155	0.800	.....	68.6	1.209	0.828	.....	68.4	1.060	0.726	.....	68.8	0.785	......
G. Nitrate of soda	67.8	1.193	0.808	0.49	68.6	1.196	0.819	0.55*	66.8	1.284	0.856	7.89	67.7	0.828	2.61
H. Ammonium sulfate	69.2	1.237	0.855	3.34	69.1	1.202	0.829	0.06	64.2	1.124	0.722	0.24*	67.5	0.802	1.05
I. Dried blood	82.7	1.282	1.060	15.79	89.9	1.227	1.101	16.58	83.6	1.187	0.994	16.27	85.4	1.052	16.21
J. ⅓ nitrogen from each	68.3	1.187	0.811	0.67	71.7	1.251	0.897	4.19	62.7	1.229	0.771	2.73	67.6	0.826	2.53
Average of 4 treated cylinders	72.0	1.225	0.884	5.07	74.8	1.219	0.912	5.07	69.3	1.206	0.836	6.66	72.0	0.877	5.60

* Loss.

dissipated. This emphasizes the importance of having a second or residual crop where a considerable part of the nitrogen is supplied in the form of organic materials. This point is well illustrated by the general averages (table 7) showing the percentage of nitrogen recovered in the buckwheat for the different materials.

In this crop, it will be noted, the double portion of potash is at a disadvantage as compared with the single portion.

TABLE 7

Nitrogen recovered—residual crop

	SINGLE PORTION K_2O	DOUBLE PORTION K_2O
	per cent	*per cent*
Nitrate of soda	4.82	2.61
Ammonium sulfate	3.72	1.05
Dried blood	20.12	16.20
⅓ nitrogen from each	9.86	2.53

TABLE 8

Nitrogen recovered—combined crops

	SINGLE PORTION K_2O	DOUBLE PORTION K_2O
	per cent	*per cent*
Nitrate of soda	54.5	52.4
Ammonium sulfate	45.6	42.6
Dried blood	49.1	44.0
⅓ nitrogen from each	48.2	41.2
Average	49.4	45.1

TABLE 9

Nitrogen recovered—combined crops for all nitrogen treatments

	SINGLE PORTION P_2O_5	DOUBLE PORTION P_2O_5	TRIPLE PORTION P_2O_5
	per cent	*per cent*	*per cent*
Single portion K_2O	56.0	47.8	44.3
Double portion K_2O	47.1	43.8	44.2

THE COMBINED CROPS—RAPE AND BUCKWHEAT

When the nitrogen data for the two crops are combined, the percentage of nitrogen recovered from the dried blood takes second rank. The average combined results for the different nitrogenous materials with the single and double portions of potash are shown in table 8.

The combined crops, as in the case of the residual crop, show a slight decrease in percentage of nitrogen recovered with the double portion of potash, as compared with the single portion.

From the standpoint of the amount of phosphoric acid used, the combined crops gave the average results shown in table 9. From these figures it will be noted that increasing the amount of phosphoric acid, slightly decreased the percentage of nitrogen recovered. The same is true with reference to the amount of potash used.

THREE-YEAR AVERAGES (FIVE CROPS)

It is interesting to compare the 1924 figures with the averages for the five crops grown during the three years. With reference to the nitrogen treatments the average results are given in table 10.

TABLE 10

Nitrogen recovered—3-year average

NITROGEN TREATMENT	SINGLE PORTION K_2O	DOUBLE PORTION K_2O
	per cent	*per cent*
Nitrate of soda	55.9	57.2
Ammonium sulfate	40.1	40.2
Dried blood	41.5	37.7
⅓ nitrogen from each	46.7	39.4
Average	**46.1**	**43.6**

TABLE 11

Nitrogen recovered for the years 1922, 1923 and 1924

CROPS USED	SINGLE PORTION P_2O_5	DOUBLE PORTION P_2O_5	TRIPLE PORTION P_2O_5
	per cent	*per cent*	*per cent*
Single portion K_2O			
1922—Barley and sorghum	48.3	62.2	60.5
1923—Corn	31.3	29.8	34.5
1924—Rape and buckwheat	56.0	47.8	44.3
General average	45.2	46.6	46.4
Double portion K_2O			
1922—Barley and sorghum	51.5	54.5	56.5
1923—Corn	28.3	32.6	31.5
1924—Rape and buckwheat	47.1	43.8	44.2
General average	42.3	43.6	44.1

The highest recovery was with nitrate of soda, with both the single and the double portions of potash. The figures are slightly higher than the corresponding figures for the 1924 crop. For the single portion of potash the lowest recovery was 40.1 per cent, with ammonium sulfate; and for the double portion

of potash the lowest was 39.4 per cent, with the mixture of the three materials. As in the case of the 1924 crops, the 3-year average shows a lower recovery with the double portion of potash than with the single, and the figures in each case are a little lower than the 1924 figures.

In connection with the different amounts of phosphoric acid used, the average percentages of nitrogen recovered from the four nitrogenous treatments, for the years 1922, 1923, and 1924 are shown in table 11. It is interesting to note the higher recovery in the years when two crops were grown than when only one was grown. In this case too, there is a higher recovery with the single than with the double portion of potash.

The general average shows a very slight increase in recovery with increase in the amount of phosphoric acid used, but since the crops of 1924 show the opposite tendency, there seems some reason for suggesting that the accumulation of phosphoric acid in the soil tends to depress nitrogen recovery.

SUMMARY

A study has been made of the availability of nitrogen in the forms of nitrate of soda, sulfate of ammonia, dried blood, and the three materials in combination, when the amounts of phosphoric acid and potash are varied.

Five crops have been grown covering a period of 3 years and two reports have already been issued. This report has to do primarily with the crops of rape and buckwheat grown in 1924.

The plan of the experiment calls for a constant supply of nitrogen furnished by the different materials with three different amounts of phosphoric acid and two different amounts of potash. The smallest amount used in each case is regarded as the normal or standard application.

With rape, doubling and tripling the standard amount of phosphoric acid, the nitrogen supply being kept constant, gave increased yields in some cases and depressed yields in others. Taking averages, the larger amounts of phosphoric acid did not materially change the yields.

Supplying a double portion of potash for the rape, depressed rather than increased the yields of dry matter in nearly all cases.

The percentage of nitrogen in the dry matter was not influenced by the amount of phosphoric acid used. With the double portion of potash the average percentage of nitrogen in the dry matter was slightly higher than with the single portion, but the difference is so slight that it is probably not significant.

The percentage of nitrogen recovered in the rape crop was slightly depressed by the larger amounts of phosphoric acid, while the double portion of potash had no appreciable effect on nitrogen recovery. For the combined crops of rape and buckwheat the double portion of potash caused a slight depression in nitrogen recovery. This tendency was also noted with the larger portions of phosphoric acid.

Taking the 3-year average (five crops), there was a slight increase in nitrogen

recovery with increase in the amount of phosphoric acid applied. For the same period the double portion of potash resulted in only slight changes in nitrogen recovery.

With the rape the nitrate of soda gave the largest yields and the highest nitrogen recovery, while the dried blood gave the lowest. On the other hand, for the residual crop (buckwheat) the dried blood gave the largest yield and the highest nitrogen recovery, but even with this high residual effect the cylinders treated with dried blood fell below those treated with nitrate of soda both in crop yield and nitrogen recovery when the results for the two crops were combined.

For the combined crops the ammonium sulfate stands between the nitrate of soda and dried blood in both yield of dry matter and nitrogen recovery.

Yields of dry matter and nitrogen recovery were higher when the nitrogen was taken from nitrate of soda alone than when taken from the combination of three materials.

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THE CHIEF FACTORS WHICH INFLUENCE THE HEAT OF WETTING OF SOIL COLLOIDS

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In a former communication (2) it was shown that a very close relationship exists between unfree water and heat of wetting and between these two and the colloidal material of soils. The heat of wetting was later tentatively suggested (3) and subsequently definitely proposed (4, 5) as a new means of determining the colloidal material in soils. Recently Anderson (1) studying the heat of wetting of soil colloids, obtained results which lead him to this same conclusion.

One of the most interesting and significant things that both sets of investigations revealed is the fact that the heat of wetting of colloids from different soils varies considerably. In the case of mineral soils for instance, the heat of wetting varies from 3.95 calories to 19.5 calories per gram, and in organic soils, such as peats and mucks it ranges from 9.63 to 37.51 calories.

The question now rises, just why the heat of wetting of the colloids from different soils should vary so greatly. Is it due to their differences in chemical composition, or physical condition, or both, or to some other factors? It is the object of this paper, therefore, to present evidences bearing upon some of the chief factors which influence the heat of wetting of soil colloids and thereby possibly to account for its variations in different soils.

PHYSICAL CONDITION

One of the chief causes and probably the most important one for the marked difference in heat of wetting of colloids from diverse types of soils, is physical. It seems that the physical condition of the colloids has a tremendous influence upon their reactivity and hence upon their heat of wetting. By physical condition is not meant merely the size of particles but also the nature of the surface of these particles, i.e., whether porous, smooth or vitrified; whether they are well decomposed or are in a state of hydration.

In table 1, are contained the heats of wetting of artificial gels of aluminum hydroxide, ferric hydroxide and silica gel, and peat, muck, and rocks. An examination of this table reveals at once the significant fact that in their natural state the colloids from the various soils give a widely different and comparatively high heat of wetting, but when these colloids are ignited at a temperature of about 800°C., their heat of wetting disappears entirely. This occurs in spite of the fact that these ignited colloids are ground so fine that

they will stay in suspension for more than 24 hours, which is the same length of time allowed to the natural colloid, and consequently the size of particles in both cases must be somewhat comparable.

The artificial hydrogels and the organic soils which give a tremendous heat of wetting in their natural state, also lose completely, with one exception, their power to produce heat of wetting upon ignition. The exception is aluminum hydroxide, which did not lose entirely its power to give heat of wetting, but was reduced nearly 75 per cent of its value.

Granite rocks and quartz which are ground sufficiently fine to stay in suspension for more than 24 hours, give only a very slight heat of wetting in their natural state and none at all after heating.

TABLE 1

Heat of wetting of colloids in their natural state and after ignition but ground again very fine

SOIL COLLOID	HEAT OF WETTING PER GRAM OF MATERIAL	
	Not ignited	Ignited
	calories	*calories*
Rhode Island sandy loam	16.280	0.0
Pennsylvania silt loam	8.226	0.0
Michigan silt loam	12.380	0.0
Michigan silt loam	10.060	0.0
Minnesota Carrington clay loam	10.550	0.0
California adobe clay	16.190	0.0
Michigan clay (U.P.)	9.070	0.0
Michigan clay (Saginaw)	12.750	0.0
Fullers earth	21.250	0.0
Peat	21.710	0.0
Muck	37.510	0.0
Granite rock	0.650	0.0
Quartz	0.450	0.0
Aluminum hydroxide	21.950	6.0
Ferric hydroxide	9.390	0.0
Silica gel	24.500	0.0

The important question now is, why do the colloids and other materials lose their property of heat of wetting after they are ignited above a certain temperature? The reason certainly cannot be due to a tremendous decrease in surface brought about by ignition, because the ignited materials cannot give any heat of wetting even after they are ground so fine as to approach the colloidal state. While it is true that the ground materials probably do not possess as great total surface as the natural materials, yet it is inconceivable to think that the surface is reduced 100 per cent as is the activity of heat of wetting.

Our present knowledge concerning the physical condition or nature of surfaces which makes material active or inactive, is very meager. It appears,

however, that when hydrated materials are dehydrated, porous surfaces are made smooth or vitrified and the activity or affinity of the material for water is greatly reduced or disappears entirely. On the other hand, soils which are allowed to undergo decomposition and hydrolysis, having formed soil particles and colloids which are in a state of hydration and have rough, porous and felt-like surfaces, have enhanced activity and affinity for water, which are probably proportional to the degree to which these conditions have progressed.

Reasoning from these facts, therefore, it would seem that the marked differences in the heat of wetting or activity of the colloids from the various types of soil as shown above can be partly accounted for by assuming that colloids from the various soils may not all represent the same degree of decomposition or maturity and consequently they do not all have the same state of hydration, porous, rough and felt-like surfaces, even though in size of particles they may not differ so greatly. Some experimental evidences seem to support these statements. Subsoil colloids, for instance, taken at a depth of 90 inches produce less heat of wetting than surface colloids taken from a 10-inch horizon. The colloids from both of these horizons were comparable both in size of particles and in chemical composition. This type of result, obtained in several soils, was examined and goes to support the hypothesis that the degree of decomposition and physical state have considerable to do with the activity of the material.

The idea of the influence of degree of decomposition upon the activity and heat of wetting is also very strikingly illustrated in the case of organic soils. For instance some peats with an enormous surface and an ash content of only 9 per cent gave only 21.70 calories per gram, while mucks which had an ash content of 28 per cent but which were well decomposed, gave a heat of wetting of 37.51 calories per gram.

In silt soils some of the particles may be as fine as those in clays but because they have not decomposed far enough, they are not so active.

This activity is manifested not only in heat of wetting but probably also in many other properties of soils, such as plasticity, cohesiveness and adsorption. Undoubtedly the rough, porous and felt-like surface of soil and colloidal particles is partly responsible for the plasticity and cohesive properties. These conditions also affect the adsorption and chemical reaction of soils. Some preliminary investigational work that has been done indicates that there might be a relationship between the colloidal content, its chemical composition and physical condition and the adsorption of various chemical substances, such as phosphorus and lime. In a general way there may be also a relationship between the heat of wetting and the productivity of soils.

CHEMICAL COMPOSITION

The second chief factor which seems to influence appreciably the heat of wetting of soil colloids, is their chemical composition. The principal constituents of soil colloids are silica, aluminum, iron oxide and organic matter.

In a former communication (3) it was shown that the heat of wetting of these constituents varies considerably. In table 1 it is shown that the heat of wetting per gram is 24.50 calories for silica gel, 21.95 for aluminum hydroxide, 9.39, for ferric hydroxide and 37.51 for muck. From this fact it would seem that the heat of wetting of colloids from different soils would vary as the proportion of these constituents varied, providing the physical condition of the colloids from the various soils were the same. In order to ascertain whether or not there was a relationship between these colloidal constituents and the heat of wetting in the case of soils, the soil colloids presented in table 1 were analyzed for these various constituents. The results obtained, however, showed only a slight relationship. An examination of certain results reported recently in various publications (1, 6) by the Bureau of Soils on the chemical composition and heat of wetting of soil colloids, seems to indicate the existence of a relationship between the heat of wetting and the proportion of the different colloidal constituents present. This relationship is shown in table 2.

TABLE 2

Relationship between heat of wetting and proportion of silica, aluminum, iron oxide, and organic matter in the colloids from different soils

SOILS	HEAT OF WETTING PER GRAM	ORGANIC MATTER	SiO_2	Al_2O_3	FeO_2
	calories	*per cent*	*per cent*	*per cent*	*per cent*
Cecil clay loam subsoil	4.5	1.40	31.84	38.28	10.04
Chester loam soil	7.2	4.11	34.82	27.88	15.93
Marshal silt loam soil	14.2	8.55	45.93	21.72	8.94
Miami silty clay loam subsoil	11.8	0.93	48.48	24.12	10.44
Norfolk fine sandy loam subsoil	6.0	1.60	38.25	31.21	11.25
Sassafras silt loam subsoil	9.8	1.59	41.14	29.26	12.93
Sharkey clay soil	16.3	3.47	50.63	20.74	9.07
Wabash silt loam soil	17.6	5.55	51.28	20.28	9.75

It will be seen readily from table 2 that a relationship does seem to exist between the heat of wetting and the proportion of the various colloidal constituents present. The figures show that the heat of wetting is greatest in those colloids which contain the highest percentage of silica oxide and the lowest percentage of aluminum and iron oxides. Conversely, the heat of wetting is lowest in those colloids containing the highest percentage of aluminum and iron oxides and lowest percentage of silica oxide. As to the aluminum oxide and ferric oxide individually, and the heat of wetting, the relationship does not seem to be very distinct, although these two constituents in the artificial condition show markedly different heats of wetting. Evidently, therefore, some other factors come in which influence the heat of wetting of these two materials. These factors may be the physical condition of the materials.

The organic matter is present in the above soil colloids only in comparatively

small amounts and consequently the relationship between it and the heat of wetting is not very pronounced in every case. The heat of wetting of organic matter approaches very closely in magnitude that of silica gel, and where both are present in large amounts the heat of wetting should be correspondingly large.

It would seem, therefore, that where no marring factors come into play, a relationship is indicated between the heat of wetting and the chemical composition of the soil colloids.

CAUSE FOR EVOLUTION OF HEAT OF WETTING

The evolution of heat of wetting represents an expenditure of energy on either one or both of the reacting materials. Since the soil colloids and other materials employed in the present investigation are comparatively quite insoluble, practically the entire expenditure of energy must be at the expense of the water alone. This expenditure of energy on the part of the water also represents a transformation in its state of aggregation probably from the liquid into the solid or semi-solid phase. In the case of solid materials which absorb water as film on their surface, the film is under great compression, and probably approaches the solid state of aggregation.

The force which causes the water to be attracted by the solid material may be due either to chemical affinity or to physical affinity or both. In the soil colloids in their natural state the attraction of water is undoubtedly due to both forces. Which one predominates is difficult to say. Since most of the soil colloids are in the hydrated state, considerable portion of the affinity for water and the consequent evolution of heat is due to the dehydration of the colloids. On the other hand, considering that tremendous amounts of heat of wetting are produced where there is no actual chemical hydration, such as in the case of carbon black and water (2) soil colloids and nitrobenzene, it becomes apparent that the physical attraction, is of no lesser importance, and in fact in many cases may be the sole factor for the heat of wetting.

It may be said, therefore, that all evidences go to indicate that the heat of wetting between soil colloids and water is a manifestation of the water undergoing a change in its state of aggregation possibly from a liquid to a solid or semi-solid phase and that the force which causes the attraction between the soil colloids and water is both chemical and physical.

SUMMARY

Evidences are reported which go to indicate that the activity of soil colloids is not only a function of size of particles but also a function of their physical condition. An active soil colloid may be made exceedingly inactive by changing its physical condition, and yet its total surface or size of particles may remain practically the same.

The physical condition involves the degree of decomposition of the material,

whether or not it is in a hydrated state and whether the surface of the particles are smooth, porous, or vitrified.

Besides the physical condition the reactivity of the soil colloids also seems to depend somewhat upon their chemical composition.

The heat of wetting of soil colloids from different soils varies considerably. This variation is attributed largely to a difference in their physical condition and chemical composition.

The relationship between heat of wetting and chemical composition is not so strongly pronounced as that between heat of wetting and physical condition, but there seems to be a relationship between the heat of wetting and the proportion present of silica oxide, aluminum oxide, ferric oxide and organic matter.

The heat of wetting is probably a manifestation of the water undergoing a change in its state of aggregation, possibly from a liquid to a solid or semi-solid phase and that the force which causes the attraction between the soil colloids and water is both chemical and physical.

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